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NOTE.

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VALUE OF ORGANIC MANURES AND INORGANIC FERTILIZERS.

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INTRODUCTION.

Hunger is the oldest enemy of man. An adequate supply of food was the most important problem in the past as it is today. Famine and starvation were frequent amongst all nations due to failure of crops and it was accepted as an unavoidable evil. Only in recent years science and technology have been systematically applied for food production in Europe and America.

The acuteness of the problem in this country will be evident from the following considerations:

It is estimated that the total world production of cereals (wheat, corn, paddy, barley, *Jowar*, *Bajra*, *Ragi* and other grains) is approximately 600 million tons. Since 1911 the cereal production in India and Pakistan has remained practically constant at 60 million tons per annum. If the cereals produced in the world were equitably distributed amongst all the inhabitants of the earth, each one of us would have 3,300 calories per day. India and Pakistan consist of 1/5th of humanity but they produce only 1/10th of the cereals. The good food materials like potatoes, milk, butter, cream, cheese, meat, fish, eggs, etc., are produced in the whole world to the extent of 400 million tons. The production of these materials in India and Pakistan is much less than 1/10th of the world production. Hence it is no wonder that India is half fed.

It is clear, therefore, that food production in this country has to go up enormously both by intensive cultivation of the land under crops and by bringing new land under cultivation.

It is apparent that the use of manures and fertilizers has to be on a larger scale than at present. The aim of agriculture must be sustained production—production and conservation together; but we are now failing to achieve this aim. Some soils are declining in fertility and humus. Some are becoming hard. Erosion is taking a heavy toll. There is great need for making the utmost of our knowledge to increase production on a sustained basis. It is necessary, therefore, to understand which form of manure or fertilizer is most suitable.

The value of animal manure in improving the productiveness of land was recognized from the dawn of human history. The relative merits of the dung of birds and poultry and of the excreta of horses, cows, goats, sheep and men for different soils and crops were fully discussed by the agricultural writers of Græco-Roman times. The benefits of composts prepared from dung, urine, straw, stalks, leaves, weeds and other trash were emphasized. Green manuring was also recommended by the Roman author, Pliny (23–79 A.D.).

It is well known that the Greek Philosopher, Aristotle (384–322 B.C.) advocated that the four elements, fire, air, water and earth, formed the material constituents of the world. He also believed that plants derived nourishment through their roots from pre-formed organic matter in the soil.

Philippus Aureolus Theophrastus Bombastus Paracelsus von Hohenheim (1493–1541), the great German Iatro-chemist, modified the doctrine of Aristotle and declared that the material world consists of the three principles, sulphur, mercury and salt.

The first experimenter to tackle the scientific aspect of agriculture was Bernard Palissy (1510–1589), the celebrated French authority on ceramics, who had fairly clear ideas regarding the importance and storing of manures and the formation of salts like nitre from manures and the value of salts in crop production. According to Glauber (1604–1668) saltpetre or nitre is the greatest of all salts, being the salt of vegetables, animals and minerals.

Palissy, Bacon, Glauber and Boyle were supporters of the doctrine of Salt advocated by Paracelsus. On the other hand, there were several distinguished men, notably Home, Wallerius, Thaer, deSaussure, Davy, deCandolle, Berzelius, Mulder and others who were advocates of the Aristotelian doctrine of plant nutrition by soil organic matter.

Lavoisier (1743–1794), the founder of Chemistry and Physiology, was impressed by the value of growing grass in improving the fertility of land. He also studied the problem of the formation of saltpetre and the construction and operation of nitre beds on soils rich in nitre.

It will be interesting to state here that in 1665 Sir K. Digby reported that he had increased the yields of crops by the application of saltpetre. Little was understood regarding the principles of fertilization until 1804, when deSaussure first directed the attention of the scientific world to the fact that the ash ingredients of plants were taken from the soil and they were essential for plant growth. About 50 years later Liebig (1803–1873) the great German Chemist and founder of the mineral theory of soil fertility laid great emphasis upon the necessity of supplying plants with phosphoric acid and potash, but he missed the value of adding nitrogenous manures to the soil and he stated the position as follows in 'Farmers Magazine' in 1847:—

'If the soil be suitable, if it contains a sufficient amount of alkalies, phosphates and sulphates, nothing will be wanting. The plants will derive their ammonia from the atmosphere as they do carbonic acid.'

The great French chemist, Boussingault (1802–1887), founder of the quantitative agricultural chemistry, emphasized the importance of nitrogen in crop production in the following words:—

'Nitrogen is the element of the highest importance which it is necessary to increase and conserve in manure. The organic substances that are most advantageous for producing fertilizers are precisely those which give birth, by their decomposition, to the largest amount of nitrogenous bodies, whether soluble or volatile.'

Lawes, Gilbert and Pugh, working at the Rothamsted Experimental Station, established experimentally in 1857 that the addition of nitrogenous manures greatly improves crop production.

Bones were used for fertilization in England in the seventeenth century.

Peruvian Guano was used in England in 1820. Although the deposits of Peruvian Guano were discovered by Count Humboldt in 1802, its fertilizing value was recognized later on. The exploitation of Chile saltpetre was begun in 1830 with the help of British capital. Ammonium salts from coal distillation were prepared and utilized in 1840. The German potash salts were first introduced as fertilizers in 1860. Liebig demonstrated in 1840 that the fertilizing value of bone is increased by treatment with sulphuric acid. The Superphosphate Industry was founded by Sir John Lawes in 1843.

A large number of distinguished agricultural chemists attached great importance to the manurial value of salts in crop production. On the other hand,

another group emphasized the importance of the organic matter or humus in agriculture and maintaining soil fertility. In the subsequent pages it will be shown that both minerals (salts) and organic matter are beneficial towards crop production.

FUNCTION AND VALUE OF ORGANIC MATTER.

It is now believed that plants can derive all their nutrients except carbon from the soil humus. Nutrients like nitrates, calcium, potassium, ammonium, phosphate, etc., can be supplied by the adsorbed matter remaining on the soil and humus surface; these nutrients are in equilibrium with the same ions existing in the aqueous phase of the soil. It is well known that the adsorptive capacity of soil humus is four times that of clay. It may be that the inorganic ions like nitrate, Ca , NH_4 , PO_4 , etc., present in the soil may be taken up by the wet humus derived from the organic matter and a part of these ions may pass into the aqueous phase to be readily adsorbed by crop roots. Moreover it has been stated that the inorganic fertilizers produce better results in soils containing more humus. It is certain that humus can supply almost all plant nutrients slowly but steadily to the growing crops. But for the supply of nitrate specially in cold countries, the humus must undergo oxidation either by better aeration or liming the material. Otherwise ammonia will be given out which may be washed away before nitrification. A soil rich in humus has not only more moisture but also it possesses porosity and a better chance of aeration which is of vital importance for plant roots. It is no wonder, therefore, that the chemists who tackled soil problems attached great importance to humus. In tropical countries the humus capital of the soil is very low and naturally the retention of inorganic salts in the soils when there is a heavy rain is likely to be endangered and hence the value of artificial manure cannot be pronounced in tropical countries with heavy rainfall. It has been observed in Malayan soils that ammonium sulphate does not improve crop production but farm-yard manure is much more profitable.

The response due to the application of ammonium sulphate in conjunction with other bulky manures like farm-yard manure, compost, etc., appears to be marked. Various experiments with green manuring have been conducted at different centres in India. Their results indicate that on poor land and lands of average fertility which is indicated by yields of 1,000 to 2,000 lbs. of paddy per acre, the response due to the application of 3,000 to 6,000 lbs. green leaves per acre is progressive. In experiments conducted at Berhampore (Orissa) a combination of green leaf with ammonium sulphate gave better yields than green leaf alone. So a green manure crop is not completely adequate in the supply of essential elements and it should be supplemented with artificial fertilizers like ammonium sulphate bone meals or superphosphates to get higher yields.

It has been proved beyond doubt that the major portion of paddy lands in India generally lack in organic matter which plays a great part in improving the fertility of soil and the primary requirement of paddy soil is nitrogen mostly in the form of humus. For tea soils Mann (1935) has stated, 'There is little evidence that liberal manuring with soluble nitrogenous manures can act as a substitute for organic matter as a source of nitrogen'. The green manures which have been successfully used in Ceylon, Java, Puerto Rico and Low Congo should be utilized in India where chemical fertilizers are yet unavailable. Crop yields can be maintained or increased by adopting better rotations by making full use of animal manures and crop residues and by using lime and green manure crops. Fertilizers are wasteful on farms not possessing a good cropping system.

One thing is clear from all European and American experiments regarding artificial fertilizers that when ammonium sulphate or nitrate or urea or sodium nitrate is added to crops with superphosphate and potash and usually with chalk yield of cereals, cotton and potatoes may be doubled using about 300-500 lbs. of

mixed fertilizers per acre. But in a poor country like India this is far too costly unless Government supplies these materials at cheap price. When the humus capital of the soil is large, as in European soils, the artificial fertilizers are effective, but, in soils low in humus, artificial nitrogen seems to be much less effective as observed by workers in Bengal and Malaya. The reason of this essential difference seems to be that the humus, i.e., the mixture of protein and lignin or other organic matter possessing high adsorptive power can adsorb the ammonium ion, the nitrate ion, phosphate ion, potash and calcium ions, etc., and these adsorbed ions are liberated slowly for the benefit of the crops during the whole period of their growth. This adsorption and slow liberation of the nutrient ions avoids leaching of minerals including nitrates of soils when torrential rain falls. On the other hand, when inorganic salts are added to soils low in humus, the adsorption and retention is much less than in humus rich soils. Consequently, the washing away is rapid when rain falls. Under certain conditions with inorganic fertilizers, the growing plant may have an overdose of minerals and this may be harmful.

Bromfield, in his 'Pleasant Valley', has stated that near his farms many agriculturists added inorganic fertilizers every year without increasing the humus capital, and in most cases, as no lime was used, the soil became highly acidic and unfit for cultivation, but on green manuring with legumes, such land became fertile again. In Rothamsted experiments no increase in the humus content has been observed with artificial fertilizers although they increase crop production. The root system left in the soil is not enough to fix atmospheric nitrogen and enrich the soil appreciably. As the efficiency of nitrogen fixation by organic substances is almost as low as the efficiency in the industrial Haber-Bosch or Birkeland-Eyde process, i.e., only 1 to 10% of the energy obtained by carbon oxidation may be utilized in nitrogen fixation by adding organic matter, hence in order to increase the nitrogen status of the soil permanently, a large quantity of organic matter has to be added.

Another method suitable specially for Europe is the addition of inorganic fertilizers mixed with farm-yard manure, straw, leaves, sawdust or coal, etc., which can form humus and to bring the carbon-nitrogen ratio to about 11 or 12 so that the inorganic matter can be retained by the humus formed for longer period, i.e. semi-permanently in the soil. It seems that the adsorption of nutrient ions by the humus and clay and their slow liberation for the benefit of crops is one of the most important functions of humus because plants require nourishment during the whole period of their growth as will be evident from the following table:

TABLE I.
Percentage of Plant Food Adsorbed per acre by Potato Plants and Tubers during each period.

Period of growth (weeks).	Nitrogen.	Phosphorus P_2O_5	Potassium K_2O	MgO	CaO	Totals.
0- 7 ..	11	6	12	4	3	9
8 ..	6	7	6	6	7	6
9 ..	10	11	12	10	8	10
10 ..	24	22	24	20	17	23
11 ..	13	14	16	15	18	16
12 ..	32	34	24	20	17	28
13 ..	1	4	5	8	17	5
14 ..	3	2	1	8	13	3
Totals ..	100	100	100	100	100	100

'Organic matter in soil' is a very general term. It includes the living forms, roots, fungi, bacteria and small animals; fresh remains of living matter, a more or

less stable decomposition product brown or black called 'humus' and a host of intermediate products. The final decomposition products are, of course, water, ash, carbon dioxide and a small amount of various gases. Perhaps the great importance of organic matter may best be realized by listing its functions in soils. The relative significance of the several items varies a great deal among different soil types. The supreme value of the addition of organic matter to soil is the fixation of atmospheric nitrogen and the preservation of the nitrogen present in or added to soil as has been established by Dhar and co-workers. The other functions have been well stated by C. E. Kellogg (1948) as follows:—

- (1) 'Organic matter promotes granular structure and pore space in some soils. Thus it may aid root extension, promote entry of water into the soil, reduce soil washing, reduce soil blowing, promote aeration or exchange of gases, increase the water holding capacity and reduce baking and crust formation.
- (2) It reduces evaporation especially when used in the surface or as a mulch.
- (3) It reduces the extremes of temperatures, especially high summer temperatures when used as mulch.
- (4) Humus aids in the maintenance of reaction (*pH*) in the soil by acting as a buffer.
- (5) Organic matter aids in the retention of soluble substances including many plant nutrients, by holding them in living or nearly fresh forms against the forces of leaching and by the base exchange properties of humus.
- (6) Part of organic matter furnishes a food supply for micro-organisms and small animals in the soil including forms essential for the transformation of nitrogen compounds and for other processes important in plant nutrition.
- (7) Organic matter furnishes directly, and indirectly by promoting bacteria and fungi, complex organic compounds which may include both growth promoting and antibiotic substances. Very little indeed is actually known about the rôle of these compounds in soil productivity.
- (8) Addition of organic matter especially from normal plants of mixed types maintain a slowly available, fairly well-balanced supply of plant nutrients including the micro-nutrients. This is very important everywhere but specially so in warm humid countries where leaching is severe and fertilizers expensive.'

GREEN MANURES AND RESIDUAL EFFECT.

The increased yields from turning under winter legume crops have ranged from 6 to 60% over the yields of check plots. In some southern states of U.S.A. cotton yields have been increased from 22 to 100% in various experiments and corn in south of America from 24 to 78%. Sweet clover is generally used in the south of U.S.A.; summer legumes are also beneficial. In middle-western states of U.S.A. residual effect has been observed for 8 to 10 years.

Carbon/Nitrogen ratio of some Organic Materials.

Material.	C/N Ratio.
Sweet clover (young)	12
Barnyard manure (farm-yard manure)	20
Clover residues	23
Green rye	36
Cane trash	50
Straw	80
Sawdust	400

Lignin makes up 40 to 45% of the total humus, and protein 30 to 35%, the remainder consists of fats, waxes and other residual matter. Phosphorus, sulphur, calcium, magnesium, potassium, iron and aluminium and other elements may be chemically bound or adsorbed with humus. Since lignin and protein account for 70 to 80% of the total humus, the formation of a lignin-protein complex suggests evidence to explain the more or less constant carbon-nitrogen ratio in mineral soil. If a ton of fresh organic matter (dry weight) in the form of green manure, farm manure or plant stubble is ploughed under or worked into the soil, decomposition begins immediately within a period of two or three weeks, under favourable conditions of moisture, temperature and aeration, only about $\frac{1}{3}$ of the original ton may remain. Many soils are too low in fertility to produce good sod, cover crop or green manuring crop. With such soil conditions it is not possible to build up the humus content unless material from outside is brought in. The humus level in mineral soils is very closely associated with the supply of the nutrient elements such as calcium, potassium, phosphorus and nitrogen.

The solubility of CaO , P_2O_5 , K_2O , MgO and other elements is increased through the effect of organic and inorganic acids produced from the decomposition of organic matter. The organic acids disappear by further oxidation.

The availability of nitrogen in ordinary farm manures is believed to be 25 to 30% of that of mineral nitrogen fertilizers but there is a residual effect; the availability of P_2O_5 and K_2O is essentially equal to that of mineral fertilizers. It has been demonstrated that the soluble humates in manure increase the solubility and mobility of mineral phosphates. Moreover, Thiamine Chloride (Vitamin B), Creatinine and other growth regulating substances are present in manure as also calcium, magnesium, sulphur, iron, manganese and other elements, which are valuable.

Data from Ohio Experimental station covering 30 years of cropping show that manure increased considerably the amounts of active calcium, magnesium, potassium, sodium and manganese in the soil compared to the quantities contained in unmanured soil. In most cases, however, even the application of 16 tons per 5 years rotation of manure did not maintain the supply of these elements at the original level. The lime requirement was not much affected by manure but all the plots were considerably more acid than at the beginning. The exchange capacity of the soil was increased.

Manure when used as a top dressing protects the soil from beating rains, decreases evaporation losses of water and appreciably improves the tilth of heavy soils. Incorporating manure with soil may be effective in reducing soil erosion by increasing the permeability of the soil to water, thus decreasing the run off losses and by increasing the density of the vegetative cover, which in turn decreases the rate of surface run off and increases water penetration. A large number of experiments has been reported showing that manure is effective in reducing both water and soil losses.

NITROGEN—THE KEY ELEMENT.

Recently Crowther and Yates (1941) have reported that the responses to phosphate and potash are substantially reduced when dung is applied but crops are equally responsive to inorganic nitrogen on dunged and undunged land. They reported large responses of crops on applying 10 tons dung per acre in absence of artificials. Thus the value of artificial nitrogen is enhanced by the addition of dung.

The question may well be raised as to why soil nitrogen content is made the basis for the fertility ratings of crops instead of phosphate or potash.

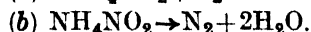
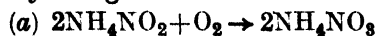
It must be remembered that nitrogen accumulates in soil in humid regions almost entirely in the forms of humus, which in turn is largely a product of the decay of plant tissues together with cells of micro-organisms. In other words,

to accumulate humus it is necessary for soil conditions to be favourable for a considerable growth of plants including legumes. This growth in turn involves at least a moderate supply of all essential plant food elements, a favourable soil reaction and drainage condition and a reasonable amount of precipitation or irrigation water. On the whole, then, the nitrogen or humus content of a soil is a fairly accurate index of productivity.

REASONS WHY GRASS LAND IS RICHER IN NITROGEN THAN FOREST OR TIMBER LAND.

Dhar (1935) and co-workers have established that when molasses, leaves, straw, sawdust, peat, coal and other carbonaceous compounds with carbon-nitrogen ratio greater than 10 are added to the soil and allowed to undergo oxidation the energy obtained by the oxidation of the carbonaceous compounds is utilized in fixing the nitrogen of the atmosphere and synthesis of proteins and in this process sunlight is actually utilized in improving the nitrogen status of soils all over the world. It is well known that prairie soils or those covered with grass or other vegetation are richer in their humus and nitrogen contents than timber soils. This may be due to the fact that more sunlight falls on grass lands and helps in improvement of nitrogen status by fixation of atmospheric nitrogen from the oxidation of carbonaceous compounds than forest or timber soils. This is a very important new consideration which has to be emphasized. Moreover, the percentage of nitrogen is smaller in acidic soils than in neutral conditions and forest soils are likely to be more acidic than grass soils.

Dhar and co-workers have proved that when nitrogenous fertilizers or proteins are added to the soils under aerobic conditions, the following changes take place: Proteins \rightarrow Amino acids \rightarrow $O_2 \rightarrow NH_3 + O_2 \rightarrow NO_2 + O_2 \rightarrow NO_3$. It is known that these changes are oxidation processes which are accelerated and favoured by increased aeration and absorption of solar light. In these processes, the unstable substance, ammonium nitrite, is formed as an intermediate product and undergoes oxidation and decomposition aided by sunlight as follows:—



The second chemical change is more prominent than the first and hence there is considerable loss of nitrogen from soils when manured with the nitrogenous compounds. This is supported by results of field trials showing that the recovery of nitrogen by crops never exceeds 50%, whilst the recovery of phosphate and potash may easily go up to 85%. Lohnis and Fred have reported the following recovery in field experiments lasting for four years:—

Nitrogen	..	P ₂ O ₅	..	K ₂ O
7.8 to 46.1%	..	10.1 to 75.6	..	22.4 to 85.1

Russell has stated that the recovery of ammonium sulphate when added at the rate of 1 cwt. per acre is as follows:—

Crops.	Average Nitrogen Recovery.			
Wheat	39.0%
Barley	47.5%
Oats	46.5%
Potatoes	50.0%
Swedes	35.0%

Manure contributes to soil productivity through both its humus content and the plant nutrients supplied which stimulate crop growth. The two contributions may be considered equal in value in increasing the humus of the soil. The Missouri Experiment Station determined the effect of 6 tons of annual application of manures for 50 years on the nitrogen content of the soil that was growing various sequences

of crops. The total increase in nitrogen content of the soil was 41.1%. As 300 tons of manure were applied, this makes an increase of 0.137% of nitrogen for each ton of manure. This is due to the fixation of atmospheric nitrogen in the oxidation of the manure.

In this connection, it is of interest to record the results obtained by White, Holben and Richen (1945) with 20 plot soils under continuous cultivation and under permanent grass. The unfertilized grass lands at the end of 72 years (1869-1940) show a nitrogen level 68.2% above the unfertilized plot soils and 42.1% above N P K treatment.

Russell (1931) has reported that the nitrogen content of a grass land increased from 0.152% in 1856 to 0.338% in 1912. Similarly a land permanently covered with vegetation for 24 years showed an increase in the nitrogen content from 0.108% to 0.145%. These results have been clearly explained by Dhar from the view-point that the cellulosic and other energy materials from the grass or other vegetation get mixed with soil and are slowly oxidized in the soil and in this process, nitrogen of the air is fixed and as copious sunshine falls on grass and prairie lands, the nitrogen fixation is much increased by absorption of solar light as has been observed by Dhar and co-workers.

LOSS OF NITROGEN FROM NITROGEN RICH COMPOUNDS.

From ancient times animal matter like blood, fish, bonemeal, tankage, wool-residues, meat-residues, guano, human excreta, etc., has been used as manure, but the mechanism of their action has been cleared up only in recent years. The carbon-nitrogen ratio of these substances is less than 10 and when they are mixed with soil, the carbonaceous compounds and the proteins are oxidized with the liberation of carbon dioxide and ammonia, which in its turn is further oxidized to nitrite and nitrate, which is the chief plant food material. The above-mentioned substances are known to be fairly quick acting manures in crop production. Researches carried on in the Allahabad University have established that when nitrogenous fertilizers are added to the soil, a good deal is wasted as nitrogen gas without benefit to the crop or soil. When 100 lbs. of ammonium sulphate are added per acre of land under cultivation, about 40 lbs. are available to the crop, but about 60 lbs. are wasted as nitrogen gas under ordinary conditions of cultivation. In our recent experiments the following results have been obtained with different nitrogenous substances:—

TABLE II.

Substances mixed with soil.	Period of exposure.	Loss of nitrogen %		Percentage loss of nitrogen in unit time (per month).	
		Light.	Dark.	Light.	Dark.
(1) Ammonium sulphate ..	2 months ..	55.5	43.2	27.8	21.6
(2) Ammonium phosphate ..	" ..	67.5	58.2	33.8	29.2
(3) Ammonium nitrate ..	" ..	28.9	21.0	14.5	10.5
(4) Ammonium tartrate ..	" ..	47.6	38.3	23.8	19.2
(5) Ammonium oxalate ..	" ..	36.6	28.6	18.3	14.3
(6) Ammonium citrate ..	4½ ..	69.9	54.8	22.1	12.2
(7) Urea ..	5½ ..	47.4	35.1	10.5	7.8
(8) Hippuric acid ..	4½ ..	42.3	23.2	9.4	5.2
(9) Gelatine ..	4½ ..	40.1	23.2	8.9	5.2
(10) Oil-cake ..	5½ ..	35.9	29.0	6.5	5.3
(11) Blood ..	6 ..	54.1	48.7	9.0	8.1

The amount of nitrogen initially present in the above nitrogenous compounds varied from about 0.25 gram to 0.5 gram in 100 grams of soil. Moreover, with such manures acidity is produced. With ammonium nitrate better results is expected and obtained because half of the nitrogen is in the form of nitrate and hence the loss is less than with ammonium sulphate. With ammonium nitrate no acidic residue is added to the soil permanently as the nitrate ion is either absorbed by the plant or leached away in the underground soil. With sodium or potassium nitrate certainly better results are expected but when the carbonaceous substance in the soil is large there is always the possibility of the formation of nitrite and perhaps ammonium salt and thus loss of nitrogen as nitrous acid and nitrogen gas specially in acid soils and there is considerable leaching with nitrates. Hence these inorganic fertilizers although they are quick-acting and readily available in our industrial civilization do not enrich the soil permanently as there is hardly any addition of humus with such fertilizers. The great advantage with such fertilizers is that they can be added to the growing crop or as a top-dressing material and no time interval is needed between the addition of the fertilizer and the sowing of the crop. The disadvantages are (1) much loss of nitrogen in the gaseous state specially with ammonium compounds, (2) the production of acidity, (3) leaching, (4) no humus addition, (5) and specially in our soil which is on the alkaline side, there is the possibility of a loss as ammonia gas.

FIXATION OF ATMOSPHERIC NITROGEN IN SOIL AND FORMATION OF HUMUS.

For over 20 years we have been utilizing different energy producing materials in enriching the soil from the nitrogen point of view. We have tried all the sugars and observed that when they are mixed with soil, they are oxidized finally into carbon dioxide and water with the liberation of energy which is utilized in fixing the nitrogen of the air on the soil surface. If the system is illuminated by sunlight or artificial light, the light is absorbed by the system and the nitrogen fixation is greatly increased. This utilization of light in enriching the soil takes place under natural conditions all over the world and appears to be next in importance to photosynthesis in plants. We have utilized all sugars, starch, glycerol, filter paper, lignin, butter, melted and clarified butter known as *Ghee* in India, and found that all these materials though may be free from nitrogen undergo slow oxidation in soil in presence and absence of sunlight. In all these cases nitrogen increase to the soil takes place without the addition of nitrogenous manures. We have also observed that molasses, press mud, plant residues, leaves, farm-yard manure, cow dung, straw, cotton-wool, saw-dust, etc., with carbon-nitrogen ratio varying from 400 to 20 not only add the nitrogen they contain but fix atmospheric nitrogen as well. The fixation of nitrogen is greater, the greater the carbon-nitrogen ratio of the energy material. In this process also sunlight or artificial light is utilized in improving the nitrogen status. Marked fixation also takes place under sterile conditions. The carbonic acid and other acids produced in this process help in making the minerals present in plant materials and in soils soluble and readily available to crops.

On the application of farm-yard manure in Rothamsted for a number of years the soil nitrogen which was originally 0.122% rose to 0.236% from 1842 to 1914. Repeated additions of ammonium sulphate or sodium nitrate did not improve the nitrogen status of soils at all. Similar results as recorded in Table III were obtained by us at Allahabad. Moreover, there is more nitrogen in the soil covered with grass than when there is no grass cover.

It is interesting to note that the percentage of nitrogen in the fields rose from 0.0386% to 0.094% after the first application of cow dung and to 0.1517% on the

TABLE III.

Soils.	Total C%	Total N%	NH ₃ N%	NO ₃ N%
(1) Not covered with grass	0.386	0.0388	0.0024	0.0012
(2) Covered with grass	0.633	0.0630	0.0039	0.0021
for months 6	0.658	0.0656	0.0039	0.0029
(3) Covered with grass for the whole year ..	0.790	0.0786	0.0051	0.0025

second addition and to 0.2000% after the third application of cow dung. The corresponding results with Neem (*Melia Azadiractta* Lina) leaf are as follows:—

Original nitrogen content .. ..	..	..	0.0386%
After first application .. ..	..	..	0.0628%
After second application .. ..	..	..	0.0815%
After third application.. ..	..	..	0.1021%

In every case the carbon-nitrogen ratio of the soil was allowed to attain the value 10 before the next application of the carbonaceous compound.

The foregoing results show conclusively that repeated applications of cow dung and neem leaf spread out in three years enrich the soil markedly by increasing its nitrogen content and humus by fixation of nitrogen and retaining the added nitrogen as well, i.e., the nitrogen of the materials added. This process is aided by absorption of solar light. By the use of municipal rubbish, the nitrogen content of the soil was raised from 0.04% to 0.25%. Excellent crops have been obtained in such improved lands.

It is estimated that 35 billion kilograms, i.e., 34,750 million tons of cellulose containing 13,750 million tons of carbon are added every year to the earth. From our experiments we find that 40% of the carbon is oxidized in our climatic conditions in four or five months and even if the same amount be taken to be oxidized on the surface of the earth in the whole year, it would mean that 5,500 million tons of carbon are oxidized every year. On a moderate estimate of 15 mgms. nitrogen fixation per gm. of carbon oxidized in sunlight about 82.5 million metric tons of nitrogen are added to the earth by fixation when 40% of the carbon

TABLE IV.

Condition.	Material used.	Period of exposure (Months).	Carbon oxidized % during the whole period.	Carbon oxidized % during one month.	Amount nitrogen fixed in mgm. per 100 gms. of soil.	Efficiency in sunlight, i.e. the amount of nitrogen fixed in milligrams per gram of carbon oxidized.
Unsterile ..	Cow dung ..	4	0.475	0.119	9.8	20.7
Sterile ..	Cow dung ..	4	0.303	0.076	4.6	15.2
Unsterile ..	Neem leaf ..	4	0.402	0.101	9.1	22.6
Sterile ..	Neem leaf ..	4	0.221	0.055	2.8	17.2
Unsterile ..	Wheat straw ..	12	0.605	0.050	14.2	23.8
Sterile ..	Wheat straw ..	12	0.319	0.026	5.5	17.4

The efficiency in the dark is half of that in sunlight.

added is oxidized. We can conclude that out of total 82.5 million tons at least 50%, i.e., 41.25 million tons of nitrogen are fixed in soils by absorption of solar light. The total output of nitrogen fixed synthetically in the factories of the world in 1937 was 3.54 million tons, i.e., 1/12th of what is obtained by fixation under natural conditions by the utilization of sunlight only with cellulosic matter.

It is interesting to note that although the velocity of oxidation of organic matter in sterile condition is smaller than in unsterile conditions, the efficiency of nitrogen fixation, that is, the amount of nitrogen fixed in milligrams per gram of carbon oxidized in sterile conditions, is of the same order as that in the unsterile experiments as is clear from the experimental results (Table IV).

ELEMENTS PRESENT IN PLANTS AND COALS.

According to G. Bertrand (1938) a flowering lucerne plant contains the following elements:

Carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, chlorine, silicon, calcium, magnesium, potassium, and sodium varying from 45.37 to 0.157% whilst the following elements are present in smaller amounts ranging from 0.0036 to 0.0000027%: iron, aluminium, boron, copper, zinc, manganese, fluorine, titanium, bromine, nickel, molybdenum, iodine and cobalt. Moreover, V. M. Goldschmidt (1935) and others have reported the presence of the following elements in coal:

Carbon, hydrogen, oxygen, nitrogen, sulphur, potassium, phosphorus, chlorine, silicon, calcium, iron, manganese, sodium, titanium, zirconium, zinc, lead, cadmium, copper, gold, silver, vanadium, beryllium, germanium, nickel, barium, gallium, strontium, boron, scandium, yttrium, lanthanum, cobalt, molybdenum, uranium, arsenic, antimony, tin, iodine, bismuth, rhodium, palladium and platinum.

ELEMENTS PRESENT IN SOIL.

A fertile soil contains the following:

Carbon, hydrogen, nitrogen, oxygen, phosphorus, potassium, calcium, magnesium, sodium, boron, copper, iron, manganese, zinc, cobalt, aluminium, titanium, molybdenum, chlorine, fluorine, iodine, sulphur and silicon.

It is clear that for the healthy growth of a crop the soil must contain those elements which form essential ingredients of plant life.

From ancient times plant materials have been partially decomposed in heaps or in pits and converted into composts which are added to the fields as manure. The aim of composting is to conserve the nitrogen present in the plant materials and add it to the soil with about 10 times its weight of carbon in the form of humus which also contains most of the mineral matters present in the plant residues along with micro-organisms.

Since 1936, Dhar has emphasized that the direct addition of plant materials to the fields before composting is more beneficial to crops, because the energy materials like carbohydrates, celluloses, lignin, fats, etc., when added to the soil, are partially oxidized and in this process nitrogen of the air is fixed and protein synthesis takes place. The value of the plant residues when added directly is due not only to their nitrogen content but also to the nitrogen fixed from the partial oxidation of their carbonaceous constituents. Hence much more humus (which is a combination of protein with lignin or cellulose or carbohydrate mixed with micro-organism) is formed and added to the soil when plant materials are mixed with the soil direct instead of their addition after composting elsewhere. The method of direct addition of plant materials to soils without composting has been adopted in farms in Pennsylvania and California, U.S.A. and England. The Citrus fruit

industry in Palestine is utilizing the direct addition of fruit and plant residues to the soil under the advice of Dhar in enriching the field.

The chief artificial fertilizers used in industrially advanced countries are potassium salts, phosphates and ammonium salts, urea and nitrates, and for acid soils, calcium carbonate. It is clear that the above fertilizers do not supply all the materials required for the healthy growth of a plant. On the other hand, plant residues when added directly, or as compost, supply all the materials needed for plant growth. Dhar and co-workers have shown that carbohydrates, celluloses, lignins and fats act as marked negative catalysts in the oxidation of proteins and ammonium salts or urea to nitrites and nitrates. Hence the proteins added along with plant materials liberate nitrate much more slowly for the benefit of the crop and for a longer period than ammonium salts or urea. The slow liberation of nitrates from humus decreases the chance of leaching away of nitrates from soil. Proteins also undergo oxidation and partially lose their nitrogen but in the presence of carbohydrates, celluloses, lignin and fats, the loss is slowed down and hence the crop can absorb the nitrate formed slowly for a longer period.

NITROGEN FIXED WITH COAL.

We have observed that peat, lignite and bituminous coal when mixed with soil in a very finely divided condition are slowly oxidized and in this process fixation of nitrogen takes place. The estimated total nitrogen capital of the world peat and lignite is 47,350 million tons. Moreover, the carbonaceous compounds present in coal are more inert than those existing in fresh plant materials, and hence, when finely divided coal is added to the soil, the available soil nitrogen is not readily converted into microbial proteins as with freshly added plant residues. Hence finely divided coal can be mixed with soil and crops can be grown almost immediately without giving any time interval which is needed when plant materials are added directly to the soil.

The growing of paddy and wheat has been found to be benefitted in our experiments by the addition of finely divided lignite and bituminous coal, which add nitrogenous manures and minerals needed for the growth of crops.

It is estimated that the nitrogen content of the humus in the top one foot of the cultivated lands of the world is 40,000 million tons. The amount of nitrogen fixed in all the nitrogen industries of the world was 3.54 million tons in 1937. Hence, the nitrogen still present in the world soils in the first foot from the top is 11,250 times greater than the yearly nitrogen production.

It is no wonder, therefore, that only 3 per cent of the world crop yield has been attributed to artificial nitrogenous manures in the last British Association meeting and reported in *Nature*, 1949, Vol. 164, No. 4171, page 597, as follows:—

‘At present only some 3% of the world food production can be attributed to the use of nitrogenous fertilizers. To raise the food by 10%, that is to say one hundred million tons, involves a fourfold increase in supplies of fixed nitrogen at an approximate capital cost of £1,50,00,00,000 (2,100 crores of rupees). This would take a minimum of 15 years to achieve.’

Thus humus nitrogen is the chief nitrogen source of the world food production.

It is interesting to note that even in the highly industrialized countries, the amount of artificial nitrogen added per acre of land before the Second World War, was much less than the nitrogen requirement of even one crop per year as shown below in pounds of nitrogen added per acre of land under cultivation:—

Belgium (28.5), Holland (24.8), Germany (15.6), Denmark (10.3), Norway (6.0), Sweden (5.24), Italy (4.3), France (4.0), Great Britain (2.5), U.S.A. (1.36), Poland (0.73) and Hungary (0.15).

Moreover, in recent experiments, Dhar and Ghildyal have shown that in composting straw with 1/8th of its weight of soil, 37% of the initial nitrogen was fixed, whilst with pine needles under similar conditions 19.2% nitrogen fixation was observed. Nitrogen fixation was also observed both in sterile and unsterile condition in composting cow dung with small quantities of soil. It appears, therefore, that when the nitrogen content of a system is not large, the slow oxidation of carbonaceous compounds in presence of small amounts of soil, leads to fixation of atmospheric nitrogen more in light than in dark.

Sewage from the city of Melbourne, Australia, is used to good effect in the Metropolitan farm, Werribee. There is plenty of scope for manuring our land with sewage water of our cities. The following beneficial results were obtained in the soil of the Metropolitan farm:—

TABLE V.
Percentage composition of dry soil.

	Before irrigation. 1912	After irrigation.	
		1924	1938
Nitrogen N	0.13	0.26	0.50
P ₂ O ₅	0.05	0.17	0.25
K ₂ O	0.15	0.80	1.09
CaO	0.06	0.32	0.39

ORIGIN OF NITRATE BED FORMATION IN NATURE.

It has been already reported that when nitrogen rich organic substances like blood, meat meal, urea, allantoin, uric acid, hippuric acid, gelatine, guano, oil-cakes, etc., are added to the soil, the nitrogenous materials are converted into ammonia and nitrates and a good deal of nitrogen undergoes loss as nitrogen gas. Hence, in the nitrification of carbonaceous compounds with carbon-nitrogen ratio smaller than 10, at least two types of substances are found: (i) nitrates like those of ammonium, calcium, sodium, potassium, magnesium, etc., depending on the concentration and availability of the minerals present in the soil, and (ii) humus, the composition of which depends on the nature of the organic substance mixed with the soil. Urea, however, does not add humus to the soil but only forms nitrates. Dhar and co-workers have shown that humus formation takes place not only by the combination of lignins and proteins but humus is also formed by the combination of microbial protein or soil or plant or animal protein with carbonaceous substances like carbohydrates, celluloses, fats, resins, waxes, etc., mixed with colloidal carbon. Hence, when blood, meat meal, fish, allantoin, uric acid, guano or other bird or animal excreta are allowed to undergo slow oxidation in air and light in presence of sand or soil or silicates, a large amount of nitrogen is lost in the gaseous state, along with the formation of sodium, potassium, ammonium, calcium, magnesium nitrates. It is clear, therefore, that the formation of nitrate beds, as in Chile, Bengal, Russia, Canada, U.S.A., and other parts of the world, is usually caused by the photo-chemical and bacterial nitrification of organic materials with a carbon-nitrogen ratio less than 10. It seems unlikely that the sea-weeds or plant materials alone, with a carbon-nitrogen ratio greater than 10, can readily form the nitrate beds as has been postulated. Sea-weed, mixed with fish or animal body or animal or bird excreta, can be the true source of nitrate beds.

On the other hand, carbonaceous substances like plant residues, straw, farm-yard manure, etc., having carbon-nitrogen ratios much greater than 10, cannot be converted into nitrates readily like compounds having carbon-nitrogen ratio less

than 10. When carbonaceous substances with carbon-nitrogen ratio much greater than 10 are allowed to undergo oxidation in soil or in sand, the carbohydrates, celluloses, fats, waxes, resins, lignin, gums, etc., are first oxidized slowly and in this process nitrogen fixation and small amounts of protein synthesis takes place. This process goes on till the carbon-nitrogen ratio of these materials becomes narrower and attain the value 10, that is, the carbonaceous materials are converted into humus. Humus when mixed with soil slowly undergoes oxidation into carbonic acid and ammonium salts which undergo further oxidation to nitrates. It is clear, therefore, that humus, formed from carbonaceous substances having carbon-nitrogen ratio greater than 10, can serve as a supplier of small quantities of nitrate. On the other hand, nitrogen rich materials like blood, meat meal, fish meal, urea, etc., when added to soil or sand can supply larger concentrations of nitrates to plants and are known as quick-acting manures and they behave as mixtures of nitrates and humus having a carbon-nitrogen ratio of the order of 10.

HUMUS AS A SOURCE OF NITRATE.

It has been definitely shown in these laboratories that the available nitrogen in tropical soils is usually more than 10% of the total nitrogen. In other words, in the alluvial soils of the Gangetic plain the available nitrogen, i.e., ammonium salts and nitrates, can be 100 lbs. of nitrogen per acre with about 1,000 lbs. of total nitrogen. In soils of temperate climates, the ammoniacal and nitric nitrogen hardly exceeds more than 2% of the total nitrogen which is usually 0.15% making about 2,500 lbs. of total nitrogen per acre. When farm-yard manure has been added year after year the total nitrogen has gone up to 0.25% in the classical Rothamsted experiments. Such dunged soils become steady suppliers of 100 lbs. or more of available nitrogen per acre for the benefit of the crop.

The addition of ammonium sulphate to soils causes the production of nitrates with loss of nitrogen in the gaseous state, but no formation of humus takes place. The introduction in soil of nitrogen rich organic substances forms nitrate and small quantity of humus, and there is also loss of nitrogen in the gaseous state. But the addition of carbonaceous substances containing small amount of protein causes only the formation of humus which in large concentration can behave as an adequate source of nitrate necessary for the proper crop growth. It is clear, therefore, that humus adds steadiness to the soil and can behave as a suitable supplier of plant food materials. From the banking point of view, the humus capital of soil formed by the addition of carbonaceous materials with carbon-nitrogen ratio greater than 10 can be compared to the fixed deposit amounts in banks, whilst inorganic fertilizer producing nitrates liable to be readily leached away resembles money in current accounts. It is evident that animal urine can be readily nitrified and forms nitrates and thus can behave as supplier of salts, but only the dung producing humus cannot be supposed to contain much salt as was done by Bernard Palissy, Glauber and ancient agricultural chemists.

SUMMARY.

- (1) Figures showing the acuteness of the food situation in this country have been recorded.
- (2) From an historical survey of the writings of the renowned chemists of the 16th, 17th, 18th, and 19th centuries, it is clear that a large number attached great importance to the manurial value of salts in crop production. On the other hand, another group emphasized the importance of organic matter or humus in agriculture and maintaining soil fertility.
- (3) Both organic matter and soil humus and salts are beneficial to crop production.
- (4) The parts played by humus in maintaining soil fertility and improvement of crop production, water retention capacity and avoiding water run off and erosion have been clearly stated:

Lignin makes up 40 to 45% of the total humus and protein 30 to 35%; the remainder consists of fats, waxes, and other residual matter, phosphorus, sulphur, calcium, magnesium, potassium, iron and aluminium and others may be chemically combined or adsorbed with

humus. Since lignin and protein account for 70 to 80% of the total humus, the formation of a lignin-protein complex suggests evidence to explain the more or less constant carbon-nitrogen ratio in mineral soil.

(5) Humus liberates nitrates more slowly than ammonium salts and other quick-acting manures and benefits the crop for a longer period. It seems that the adsorption of the nutrient ions by humus and their slow liberation for improving crop production is one of the most important functions of humus, because plants require nourishment during the whole period of their growth.

(6) The reasons why nitrogen is considered as the key element in plant production have been stated.

(7) An explanation has been given as to why the nitrogen content of forest and timber soils is less than in grass soils.

(8) The various processes by which nitrogenous fertilizers undergo nitrification are accelerated by aeration and absorption of solar or artificial light and there is marked nitrogen loss in nitrification. This conclusion is supported by results of field trials showing that the recovery of nitrogen by crops never exceeds 50% while the recovery of phosphate and potash may easily go up to 85%.

(9) Experimental results have been recorded showing marked loss of nitrogen in the gaseous state by the addition of ammonium salts and other quick-acting nitrogenous fertilizers to soils.

(10) When plant materials, farm-yard manure, straw, saw-dust etc., with carbon-nitrogen ratio greater than 10, are added to the soil, the fixation of atmospheric nitrogen and protein and humus formation take place. The addition of humus to soil by this process is much greater than when such substances are added to soil after composting them elsewhere. It has been observed that sunlight or artificial light is utilized in nitrogen fixation and humus formation and that the greater the carbon-nitrogen ratio of the starting material the greater is the nitrogen fixation and formation of protein and humus. This fixation is the chief source of soil nitrogen and the main function of the addition of organic matters to soils. In composting straw, pine needles, cow dung, etc., with small amounts of soil appreciable nitrogen fixation is observed, more in light than in dark.

(11) Much more nitrogen is fixed in the arable soils of the world by the absorption of solar light per year than the nitrogen fixed in all industrial operations. This nitrogen fixation can take place under completely sterile condition both in light and dark, more in light than in dark.

(12) The greater the fixation of nitrogen and humus formation in the soil, the greater is the residual effect of the manure.

(13) The efficiency of nitrogen fixation by the addition of organic substances is as low as the efficiency in the industrial Birkeland-Eyde or the Haber-Bosch process. Not more than 1-10% of the energy obtained by the oxidation of the carbonaceous substances is utilized in nitrogen fixation and protein synthesis by adding organic matter. Hence in order to increase the nitrogen status of the soil permanently, specially in tropical countries where oxidation processes are vigorous, a large quantity of organic matter has to be added.

(14) On the application of farm-yard manure in Rothamsted for a number of years the soil nitrogen which was originally 0.122% rose to 0.236% from 1843 to 1914. Repeated additions of ammonium sulphate or sodium nitrate did not improve the nitrogen status of soils at all. Similar results were recorded at the Missouri Experimental Station. We have been able to obtain exactly similar results at Allahabad when the total nitrogen in fields rose from 0.0386% to 0.094% after the first application of cow dung and 0.1517% on the second addition and to 0.200% after the third application of cow dung spread out over three years. By adding municipal rubbish with a carbon-nitrogen ratio much greater than 10, the nitrogen content of a soil increased from 0.04% to 0.25% and produced a bumper crop.

We have also shown that there is more nitrogen in soils covered with grass than in land without a grass cover.

(15) Another method for improving the nitrogen status is the addition of inorganic nitrogen fertilizers or urea mixed with carbonaceous substances like farm-yard manures, straw, leaves, saw-dust, peat, lignite or bituminous coal which can form humus and to bring the carbon-nitrogen ratio of the mixtures to 11 or 12 so that the ammonium and nitrate ions can be retained by the humus formed for a longer period in the soil.

(16) Considerable quantities of humus are present in peat, lignite and coal. These materials improve crop production by their slow liberation of nitrate and fixation of atmospheric nitrogen. These are also beneficial to alkaline soils.

(17) The method of direct addition of plant materials without composting is easier and more profitable as there is nitrogen fixation and more humus formation than composting, and has been adopted in farms in Pennsylvania and California, U.S.A. and Great Britain and by the citrus fruit industry in Palestine.

(18) Only three per cent of the world food production has been attributed to artificial nitrogenous fertilizers. Thus humus nitrogen is the chief nitrogen source of the world food production.

(19) The pounds of artificial nitrogen added per acre of land under cultivation varies from 0.15 in Hungary to 28.5 in Belgium and is much less than that required for the production of one crop per year.

(20) When blood, meat meal, fish, hippuric acid, uric acid, guano or other bird or animal excreta are allowed to undergo slow oxidation in air and light in presence of sand or soil or silicates, a large amount of nitrogen is lost in the gaseous state along with the formation of sodium, potassium, ammonium, calcium, magnesium nitrates, etc. It is clear, therefore, that the formation of nitrate beds as in Chile and other parts of the world is caused by the photochemical and bacterial nitrification of organic materials with a carbon-nitrogen ratio less than 10. It seems unlikely that the seaweeds or plant materials alone with a carbon-nitrogen ratio greater than 10 can form the nitre beds as has been postulated. Seaweeds mixed with fish or animal body or animal or bird excreta can be the true source of nitrate beds.

On the other hand, carbonaceous substances like plant residues, straw, farm-yard manure, etc., having carbon-nitrogen ratios much greater than 10 cannot be converted into nitrates readily like compounds having a carbon-nitrogen ratio much less than 10. When carbonaceous substances with carbon-nitrogen ratio much greater than 10 are allowed to undergo oxidation in soil in sand, the carbohydrates, celluloses, fats, waxes, resins, lignin, gums, etc., are first oxidized slowly, and in this process nitrogen fixation and small amounts of protein synthesis take place, and the synthesized protein and the protein added with the plant materials are protected by the carbohydrates, fats, etc., from rapid nitrification and partial loss.

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THE SOIL FERTILITY PROBLEM OF INDIA.

By H. MARTIN-LEAKE.

(Communicated by Prof. N. R. Dhar, F.N.I.)

It is with some demur that I have acceded to a request that I contribute a paper to this Symposium, for it is long since I have been actively engaged on research, and I have, therefore, nothing new to offer. But there are two old sayings. One of these refers to the difficulty of seeing the wood for the trees; and it is true that one who is engaged on studying a specialized problem—and science now covers so vast a field that all active investigators are of necessity specialists—runs a risk of failing to see how his particular problem fits into the generalized pattern. The other is that it is the spectator who sees most of the game. It is these considerations which have led me to accept the invitation, and it is as a spectator only that I contribute the following views on the relative merits of organic and inorganic manures.

The use of inorganic, or artificial manures is a product of the West and followed from the work of Liebig. That development has divided the world into two. In one section the use of artificials has become standard practice, in some extreme cases to an extent that the use of organic manure is completely discarded; in the other artificials have not yet been introduced. Broadly speaking, these two sections may be defined as West and East, though the distinction is not so clear cut. In Africa, for instance, alongside the settled tracts where the latest cultural practices are adopted, are tracts with the most primitive agricultural system of all—shifting cultivation. Shifting cultivation side-tracks the question of manuring, for a new virgin tract is opened up as soon as the old one becomes exhausted. But in India and China, typical of the East, pressure of population has led to the development of a system of permanent cultivation of a very skilled type not based on artificials, a skill which is the outcome of the necessity for maintaining a permanent level of fertility. Climatic differences naturally dictate certain differences in the practice adopted, but the major human-controlled factor lies in the extent of the use made of organic residues, particularly human residues. It is the economic circumstances and not lack of skill which forms the limiting factor in India. The need for feeding his family and stock and for producing cash crops to buy the bare necessities which his holding cannot produce, has forced the Indian peasant to feed his straw to his cattle instead of growing a rotational fodder crop and to use their droppings as fuel. If his yields are relatively low, it is for this reason and not through any lack of skill, the measure of which is the nice adjustment between the amounts removed as crops with the maintenance of a certain standard of permanent fertility. With a lesser degree of skill, fertility would have been destroyed and a desert produced.

But India is now at the cross-roads. Her rapidly increasing population, combined with the absence of any extensive fresh areas available to be opened up for cultivation, since the major sources of irrigation are already developed, is creating a demand for food which can only be met by the rather precarious dependence on external sources of supply or by an increase in the average yield obtained from an acre, the latter objective only to be obtained by raising the level of fertility permanently. It is natural, seeing the apparent increase in production in the West through the use of artificials, that attention should be directed to this method as a solution of India's problem.

Before embarking on such an imitative course, however, it is very desirable that those responsible for taking the decisions involved should scrutinize carefully

the evidence of the West. Though artificials have long been in use in the West, it is only in the last half century that their growing use has reached a degree likely to produce, in association with the decrease in the use of organic manures, an appreciable and measurable effect. Here there is at once met a difficulty; what can be accounted acceptable evidence? That artificials can, and do lead to large, sometimes very large increases in yield is undoubted; millions of experiments, conducted all over the globe and under very divergent conditions prove this, and in commercial practice their use has become general. But these facts hardly provide adequate, and certainly not conclusive evidence. The vast majority of these experiments measure only the short term effects; what is of concern here is the permanent level of fertility, and this is a long term effect. The very fact that so many experiments are devoted to determining the residual effect over a year or two is suggestive. Is it possible, then, to trace a trend in the general level of fertility under a continuous system using artificials? Where meteorological conditions vary so widely from year to year, with their direct effect on yield, the statistically conclusive evidence is naturally hard to come by. Nor is that the only obstacle. In recent years there has been an outpouring of varieties which, selected as these are for their capacity to give higher yields through better adaptation to local conditions, necessarily introduces a further complication in any statistical analysis. Furthermore, there is suggestive evidence that the continuous raising of seed under conditions which neglect the humus factor, leads to a progressive debility which finds expression in ill-health and it is neglect of this possibility that rules out that longest series of experimental trials, those at Rothamsted, as offering conclusive proof.

It is not here possible to review that growing mass of evidence indicating that humus is the most fundamental factor affecting healthy growth and, through it, yield. That mass of evidence, embracing the growing incidence of disease, the running out of varieties and so on, is amply recorded in the literature on the subject and is sufficiently weighty to carry conviction to most impartial minds even if each observation is not conclusive in itself and fails to provide the ultimate proof demanded by modern statistical analysis. Here I can only outline that evidence which most nearly fulfils the rigorous conditions of such analysis.

South Australia possesses a climate characterized by low rainfall; from 8" to 20" with only a fraction of the area here dealt with exceeding 16". The wheat belt here by 1886 contained nearly 2 million acres under that crop which, by 1930, reached a maximum of 4 million acres. A very detailed statistical analysis of 'The Yield Trends in the Wheat Belt of South Australia, 1896-1941' has been made by E. A. Cornish.¹ By the division of the area into units according to the length of the period under cultivation and by the elimination of such variable factors as rainfall and types of soil, he isolated a positive trend in yield due to the factors (a) maintenance of an adequate phosphorus and nitrogen supply, (b) the adoption of cultural practices suited to the various types of soil, (c) the use of improved varieties, and (d) the maintenance of the physical condition of the soil, and a negative trend due to a reduction in fertility consequent on agricultural exploitation of the soil. With regard to this reduction in fertility he comments 'this (the negative trend) has proceeded so far in some areas that it outweighs the beneficial effects of recent advances and results in a progressive decline', a decline which has gone so far that a Pastoral and Marginal Agricultural Inquiry Committee in 1948 recommended the abandonment of wheat growing as the major operation in these depleted tracts. In attempting to trace the cause of this loss of fertility, he is led to the conclusion that it is due to the depletion of the organic reserves of the soil, affecting both the nitrogen and water supply.

¹ *Australian J. Sci. Research*, 1949, Series B, 2, pp. 83-137.

The second paper to which I would draw attention, comes from Hawaii. Hawaii has attained the proud position of producing more sugar per acre than any other country. It has done this by organizing within an industry run on a plantation basis a highly efficient technical service applying all the latest teachings of science. Yet, as L. D. Bayer shows,¹ all is not well with the cane sugar industry of Hawaii. Among the factors accounting for this leadership is the varietal programme; yet none of the new varieties have fulfilled their promise when brought into commercial use. Under such conditions, the initial rise in yield is followed by a levelling off and, ultimately, a retrograde movement, and this in spite of the concurrent ameliorative conditions. Here is to be seen that process which has been so characteristic of the sugar industry of all countries, the running out of varieties with the consequent necessity for their replacement at ever shorter intervals. And this is not a phenomenon inherent in the new varieties; it was the running out of the centuries-old standard varieties that gave the urge to varietal breeding once it was recognized that the sugar-cane set seed.

But Bayer carried his investigation to cover a wider field, giving the results of an analysis of crop yields in Ohio. He gives, in the form of a 'productivity index', a percentage loss or gain per annum for various crops. This, for crops like maize, grown in rows, is -2.0. He further states that the cropped lands have lost about one-third of the original organic content and that a cubic foot contains about 22 per cent more soil than originally, with a consequent reduced aeration. He sums up his conclusions in words almost identical with those written by Cornish: 'The natural productive capacity of the soil has been deteriorating at a rate almost fast enough to offset all the improvements in soil and crop management.' Here, again, the cause of the deterioration is attributed to neglect of the organic factor. Though this case is not recorded with the same wealth of statistical proof, it has a technical value which is convincing. Under the very divergent conditions of South Australia, Hawaii and Ohio, the same conclusion is reached; it is the neglect of the humus factor which is the prime defect in the modern approach to cultural problems. Through this neglect, the farmer is advised to spend more and more on artificials merely to find that he has to face further expenditure for dusts and sprays to check the diseases attacking a debilitated crop.

What is the lesson to be drawn by India from the above? She differs from what has here been termed 'The West' in the fact that artificials have, as yet, not been incorporated in her agricultural practice. Her problem differs in consequence; in both cases, the need is for greater attention to the organic status of the soil, but the approach is different. In the West it is a retreat from an excess of artificiality in agricultural practice to a nearer approach to Nature; in India it is a restoration of those organic materials of which the soil has been deprived through the more pressing demands of a dense population. The average fertility of her soils is, in consequence, low and must be raised to a higher permanent level if the needs of her growing population are to be met. The temptation to take the easier apparent solution through resort to the wide use of artificials is great, though that raises economic and financial questions of no mean order, but she will do well to study closely the experience of the West before doing so. The mass of evidence now available justifies the belief that, with attention to the organic status of her soils, a soil fertility can be built up and maintained at a level which will give yields equal to those now obtained temporarily by the use of artificials. That is no dogmatic statement. It is reasonable to suppose that there are exceptions when certain deficiencies will limit yields, but the requirements of exceptional cases should not form the guide for general practice.

India will do well to press on with her well-founded plans for the return of all organic wastes and to mark time with her plans for the bulk production of artificials

¹ *Hawaiian Planters' Record*, 1949, 53, pp. 1-12.

through hydro-electric development—that power could be used to better purpose—and she will be well-advised to search out other sources of organic matter. And here it is possible to make a very tentative suggestion, the practicability of which is quite unknown to me but may be worthy of investigation. India has a wealth of coal, much of which is of low calorific value. May it not be possible to develop this wealth by a process of distillation to yield gas and volatile products sufficient to cover cost, leaving a residual fuel to be distributed at nominal cost? Thus might be overcome the present need for burning cattle droppings which would become available for composting with other residues of the peasant's holding. The higher fertility would release part of the holding for fodder crops, in turn releasing some of the straw for composting.

So far, I have considered the practical issues. There remains the more fundamental problem of the exact rôle played by organic matter in the development and maintenance of fertility. Much has to be learned before anything more than a broad answer can be given to this complex problem. As is so often the case in matters of this complexity, it is empiricism and analysis which relates cause to effect. That dictates practice, while science only later finds the explanation of that relationship. On this aspect I can touch only lightly.

The soil can be considered from three angles, chemical, physical and biological; and organic matter plays a rôle in each. But its especial rôle is biological, for it is organic matter that supplies the energy required by that teeming soil population which justifies for the soil the adjective 'living'. By a series of steps starting in the eighties of last century, a generally accepted interpretation has been arrived at which ascribes to the biological activities of the soil organisms the breaking down of nitrogenous organic matter and the fixation of free nitrogen. The nitrogen cycle, in the course of which nitrogen is rendered in a form available to the plant, is a biological phenomenon. But Nature works by devious routes, and N. R. Dhar and his associates at Allahabad, as the result of work covering a number of years, have obtained results strongly suggesting that, under the influence of light and especially light of an intensity found in the tropics, an a-biotic fixation of nitrogen takes place, and to an extent that would add materially to the supply of available nitrogen. That this work should have received so little attention is, perhaps, only in accord with expectation; a biological interpretation of the nitrogen cycle so long accepted as satisfying will not be discarded lightly. A-biotic fixation adds complexity to the nitrogen cycle; fixation, biotic and a-biotic, will take place concurrently in the soil and the problem arises of unravelling the two. Particularly, it may be asked, what is the relationship of each to the seasonal rise in nitrogen fixation during the hot weather and following the rains, hitherto considered adequately explained as biological phenomena? But if much remains to be discovered as to the exact rôle of a-biotic nitrogen fixation, one fact already stands out; the presence of adequate organic matter is as important in one case as in the other. The major practical problem remains the same; the organization of an adequate supply of organic matter for addition to the soil. A better understanding of the forces, both biotic and a-biotic, at work will form the basis for the determination of the optimum manner in which organic material may be used.

Let me conclude with a quotation from an unpublished record of the late G. Clarke, contained in some writings of his which have recently come into my possession. Though nearly twenty years have passed since he left India, his work on sugar-cane in the United Provinces has, perhaps, not been entirely forgotten. He wrote as follows:

The weather produces conditions which give rise to seasonal biological activity in the soil differing in some respects from that occurring in the temperate climate of Europe. The final result of biological change is the accumulation of nitrate which is the important factor determining yield. In England this takes place gradually during the spring and early summer under the influence of slowly rising

temperature. In North India the accumulation of nitrate reaches a peak point twice during the year before the break of the monsoon and the sowing of the summer crop, in June, and again at the end of the rains, as the soil slowly dries and becomes aerated by the cultivation for the winter crop. In the hot weather the nitrate is produced very quickly in a few weeks, and in much larger quantity than in the cold season. Nearly all of it disappears from fallow land after a few heavy falls of rain, but it is not entirely leached out of the soil as one might at first sight suppose. Under the influence of high temperature and ample moisture, a subsidiary nitrogen cycle is set up. There is intense fungal growth in the soil and a large part of the nitrogen passes into fungal tissue. It is immobilized and packed away for future use. The rapidity with which the nitrogen cycle operates under tropical conditions constitutes the fundamental difference between tropical agriculture and that of colder climates.

I had often to reply to arguments which maintained that the productivity of the soil had decreased. The records of the United Provinces did not support this view and, indeed, it was not to be expected.

It is true that Indian soils contain a very small amount of humus and nitrogen compared with the soils of colder and moister climates. The oxidation processes are so intense that only resistant forms of nitrogen are left in the soil organic matter which have been put out of action, namely reduced to a state in which further change is extremely slow. The crops obtain very little from this resistant material and cultivation has not much effect on it. There is no accumulated fertility in India, but this does not mean that the land is incapable of producing crops or that the yield cannot be raised. The capacity of the soil to maintain the underground life necessary for healthy crops depends on a smaller quantity of humus and nitrogen (75 to 100 lbs. per acre) which is in constant circulation and constantly undergoing transformation. Some of it is removed every year by the crops. Twenty to thirty are washed out at the beginning of the rains. Much of it is immobilized and passes into fungal tissue to become available later when the fungi die and decay. The supply is replenished every year by non-symbiotic fixation, the energy necessary being provided by the freshly prepared humus produced annually by the decay of roots and weeds.

This small quantity of freshly made humus and the active nitrogen that it contains is the working capital of the Indian cultivator and the foundation of the ancient system of Indian agriculture, which has established a perfect balance between the removal of fertility by the standard yields and the recuperative processes of the soil. By this method of farming the productivity of the Gangetic plain is inexhaustible.

Agriculture in the United Provinces can be raised to a level three times higher than at present, as I showed in the most conclusive manner at Shahjahanpur. For over twenty years 100 mds. of sugar and 26 mds. of wheat per acre were obtained. The average yields in the United Provinces were 30 maunds of sugar and 10 maunds of wheat per acre. This result depended on raising to and maintaining at a high level the balance between soil aeration, organic matter, plant food and variety.

His comment on the danger attending the introduction of artificials into this delicately balanced system has been recorded by me before, but is worth repeating:—

Short cuts to increased production such, for example, as the excessive use of artificial nitrogenous manures, under the conditions which prevail in the United Provinces are attended by the gravest risks.

Irreparable damage can be done to the magnificent soil which for thousands of years has been the wealth of India. Its recuperative power, namely, its power to fix nitrogen by non-symbiotic processes, which is increased by rational methods of intensive cultivation, will be destroyed and more and more

artificial will have to be used. A state of affairs will inevitably arise in which the active soil organic matter will be used up during the attempts of the organisms to deal with the unnecessary nitrogen. Desert conditions will make their appearance, accompanied by alkalis which will put a stop to cultivation of any kind.

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ORGANIC *VERSUS* INORGANIC MANURES IN LAND IMPROVEMENT AND CROP PRODUCTION.

By B. VISWANATH, New Delhi.

The question of organic and inorganic manures and fertilizers is of the greatest interest at the present time in view of the urgent call for manuring for increased crop production.

The question is what system of manuring is the best, initially and in the long run, for soils, men and animals. In other words, how to grow more and better crops. In the year 1926, Viswanath and Suryanarayana in collaboration with R. McCarrison published the results of their studies on crops manured with organic and inorganic manures. Their results showed the importance of nutritioning the soil first for nutritioning the plant and through the plant the animal and in this respect organic manures were superior to chemical fertilizers. Since then two schools of thought developed, one favouring organic manures and the other mineral fertilizers. The answer to the problem lies in the knowledge and field experience gained during the past years, in the science and practice of manuring and plant nutrition.

Based on the mineral theory of Liebig, the chemical treatment of the soil was the dominating idea underlying the theory and practice of manuring in India, forty or fifty years ago. According to these ideas one had only to make a chemical analysis of the soil and to make the deficiency by the addition of the mineral salts indicated by analysis, to maintain the fertility of the soil. Experiment and experience has gradually changed the ideas. The whole problem has been slowly but steadily getting clarified by researches in soil science and plant science, and has, in recent years, brought about new knowledge and new outlook. The soil processes and the carbon-nitrogen and other organic and mineral cycles are becoming clearer and mineral or artificial fertilizers have begun to fall in their place as important but not as all important. The new outlook includes in its horizon, the direct and indirect effects of organic manures on crop growth and a consideration of plant growth in terms of the major biological cycle—micro-organisms—plant—animal—micro-organisms.

The scientific and practical aspects of the work of Viswanath and his associates may be briefly stated thus. It has been shown by experiments with Indian crop plants that:

- (1) There is a close resemblance in the nutritional needs of plants and animals.
- (2) Organic manures and organic matter, function directly in plant nutrition in a manner analogous to that of vitamins in animal nutrition and that a closer and direct connection exists between the micro-organisms in the soil and the plants growing therein.
- (3) Micro-organisms liberate from the added organic matter and from their bodies an active constituent which is absorbed by the plant and passed on to the seed, thus influencing the nutritive and reproductive value of the seed.
- (4) Plant metabolism and protein make up and the nutritive value of crops vary with the nutritional factors available to the plant.

In a later publication in 1932 Viswanath stated thus:

‘The response to vitamins and the capacity to synthesize thus appears to be universal from the simplest unicellular organism to the most complex

multicellular organisms.... It seems, therefore, reasonable to state that plants and bacteria do normally require auximones or vitamins and if they can get them in a readily available form they utilize them; if not they exercise their powers of synthesis.

In 1937, *Nature* reported that the Royal Society held a discussion and concluded that it appeared from the available evidence that the case established in the nutrition of animals is equally established in the nutrition of the most diverse varieties of cells, namely, that all cells from the lowliest bacterium to the cells of the highest animals are enabled to carry out the series of reactions between the sources of agency and nitrogen which result in the production of energy and growth, only by the agency of other substances mostly of a nature akin to those already described in animal metabolism—vitamins. The only notable difference between the various forms of life is that these accessory substances are normally synthesized by some cells and not by others.'

In 1942, M. Copisarow reviewed the more recent work on the differentiation between natural and artificial fertilizers. He noted that recent researches have shown that the contrast between natural and artificial fertilizers goes beyond the colloidal and nutritive properties of the soil organic matter derived from organic manures, and that certain organic compounds and complexes contained in the soil lies in their physiological function—growth promoting and protective agents. The combined effect of the growth promoting and protective agents in the humus in conjunction with the activity of nitrogen-fixing organisms leads to the general well-being of the plants both by improved nutrition and disease resistance. In this respect Copisarow observes that the environmental influence of the remains of past organic life as modified by the micro- and macro-biology of the soil, in determining or influencing form and function of the emerging new growth is reminiscent of and certainly complimentary to the hereditary—influences occluded in the seed or the chemical orientating force exercised in the organizer cells.

In 1950, K. I. Semergei reports that cotton plants grown with high nitrogen nutrition gave seed which retarded plant growth in the third generation, while high phosphate nutrition had a stimulating effect. The author observes that the results of his experiments indicate that a particular form of manuring carried for two to three generations alters the nature and behaviour of the plant.

A review of manurial experiments carried out in different parts of India and reported in journals, bulletins and annual reports shows that the most responsive crop was paddy (rice), the least responsive was cotton. Other crops like sugar-cane, wheat, tobacco, millets occupy intermediate positions. The biggest controlling factor in these cases of differential responses between the different crops, is the supply of moisture in the soil. If this is lacking manuring particularly with chemical fertilizers does more harm than good. In regard to the manures themselves, the broad inference that may be drawn from the data, is on the general usefulness and superiority of organic manures and their importance in any system of manurial treatment for any crop. There is a very strong indication that in the presence of organic manures, there is better utilization of artificial or chemical fertilizers. There is also the indication that the availability or utilization of organic manures is stimulated by the presence and action of artificial fertilizers. Organic manures have also been found more beneficial to soil tilth than artificial fertilizers. Besides this, organic manures have to undergo micro-biological changes in the soil before they are ready to be utilized by the plant. The plant, is in consequence fed more steadily and continuously, than with artificial fertilizers which become available to the plant in a rush. Here then is the advantage of organic manures over artificial fertilizers for the majority of Indian soils.

In our country, because of the rapid destruction of organic matter that occurs in soils, it is advantageous to use organic manures in association with small

quantities of chemical fertilizers. The basic principles underlying such associated use may be briefly described thus:

Manures like farm-yard manure or green manure contain on dry basis about 2.2% nitrogen and 40% carbon. When these manures are incorporated into the soil the substances undergo micro-biological decomposition and ultimately become part of soil humus. In this process of fermentative decomposition loss of some nitrogen and more of carbon occurs and ultimately the final product contains about 20% of carbon and about 2% nitrogen. That is, the process stabilizes round about the theoretical C : N ratio of 10 : 1. There being initially a large excess of carbon, the micro-organisms will require nitrogen for the continuance of their life cycle and life processes.

If on the other hand a chemical fertilizer like ammonium sulphate is applied to the soil some loss of nitrogen has to take place to get near the ratio of 10 : 1 unless there is available in the soil sufficient organic matter to supply the carbon required by the micro-organisms.

It is to this fermentable or decomposable carbon of the organic manures, that the valuable interaction between organic manures or artificial fertilizers is due. The nitrogen held by the carbon or humus is gradually released for the benefit of the plant and before this release takes place the nitrogen is protected from loss by leaching action.

The proportions in which organic and inorganic manures should be used in conjunction will depend, on the organic matter content of the soil, and on the composition of the manure. For instance the amount of inorganic fertilizer to be used with groundnut cake will not be the same as with farm-yard manure.

In 1940, E. John Russell and J. Watson reviewed the results of Rothamsted and Woburn experiments and the conclusions in respect of organic manures and inorganic fertilizers were:

- (1) Average yields are approximately the same with both.
- (2) Seasonal fluctuations in yield are smaller on the farm-yard manure plots than in mineral fertilizer plots.
- (3) Deterioration in yield with time is slightly lower in farm-yard manure plots than in mineral fertilizer plots.

These, in the main agree with those in India and the most important point is that farm-yard manure maintained steadiness in yields, which artificial fertilizers did not. The review in 1941 by A. L. Prince and his associates of 40 years of American experiments has shown that the only plots that did not deteriorate in fertility (as judged by N content or organic matter content and pH) were those that were systematically treated with farm-yard manure annually and periodically limed and green manured.

There is thus considerable evidence regarding the value of organic manures in any system of agriculture particularly in the *dry tropics* and *sub-tropics*.

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SOUTH AUSTRALIAN EXPERIENCE WITH INORGANIC FERTILIZERS.

*By J. A. PRESCOTT, Waite Agricultural Research Institute,
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(Communicated by Prof. N. R. Dhar, F.N.I.)

The outlook towards fertilizers in Australian agriculture is determined by two main factors—the low density of population and the relative poverty of many of the virgin soils in the elements required for plant nutrition.

The first determines the low availability in quantity of any form of organic manure and the second determines the actual volume of production of organic matter as plant material by the soil under natural conditions.

The mild winters also mean that few stock are housed and this is accentuated by the increasing mechanization of transport and farm operations.

Under the conditions prevailing in southern Australia, where the problem has been most closely studied, for each particular level of soil phosphate there is a sequence of vegetation associations starting with the most arid and finishing with the most humid. In South Australia with a rainfall of 20 inches per annum, principally effective in winter, there may occur either, savannah woodland, a sclerophyll woodland or a sclerophyll heath or scrub depending on the phosphate content of the soil. Some of these soils have never been used for agricultural purposes and have a very low carrying capacity for livestock.

The amount of organic matter present in the virgin soil is strictly proportional in these cases to the level of inorganic plant nutrients measured as phosphate. In one locality (Keith: annual rainfall 17.9 inches) the amount of nitrogen in the top two inches of virgin soil was found to be six times the amount of acid soluble P_2O_5 present over the range 0.002% to 0.025% of P_2O_5 . Such soils are exceptionally poor in phosphate, particularly when one considers that soil derived from basaltic parent material may contain up to 0.50% of P_2O_5 .

These soils, although deficient in phosphate are not necessarily deficient in potassium but the first deficiency carries with it other deficiencies, particularly among the micro-elements and the improvement and economic utilization of these lands has in fact had to await the discovery of the importance of these microelements for agriculture.

The most logical explanation of the low values for mineral nutrients in these soils is that the parent materials from which they are derived have undergone a number of cycles of weathering, losing something in each cycle. Thus it is estimated that in each cycle of weathering of a rock about 35 per cent of the phosphate is lost in the drainage waters and finds its way to the oceans. If at each cycle of weathering of the resulting sediments the proportion of loss remains the same then the amount of phosphate present in the end product can be estimated from the following expression:

$$x = a(1 - 0.35)^y$$

where x is the amount of phosphate in the end product,

a is the amount of phosphate present in the original parent rock, and

y is the number of cycles of weathering.

It is probable that in South Australia most soils are derived from sediments that have undergone from three to six or more such cycles.

Before we can consider therefore the relative importance of organic or inorganic manures in these soils it is important to build up the level of inorganic nutrients so

that biological activity of all kinds can proceed at a much higher level than is occurring naturally.

Another feature of importance in parts of Australia is that the soils are relict from wetter climatic periods occurring probably in Pliocene times. These soils are often associated with formations of laterite. Not only are they depleted, by leaching, of mineral nutrients but some of these latter may be locked up in the laterite itself, by combination or association with the iron oxide.

At the present time the Department of Agricultural Chemistry at this Institute is engaged in the detailed study of the plant responses to inorganic fertilizers on one such soil: the *Seddon gravelly sandy loam*. This soil is grossly deficient in both phosphate and nitrogen and remarkable responses are obtained to both these fertilizers in the very first year of development from the native heath vegetation.

Plants grown on this soil also show responses to potassium and copper and micro-elements other than copper may also be concerned.

One remarkable feature of the soil is its low microbiological activity—such processes as nitrification are exceedingly slow and presumably before any decomposition of organic matter can take place it will be first necessary to build up the level of inorganic plant nutrients.

The practical method of land improvement on these soils when once the mechanical operations of clearing are completed is the growth of pastures containing as the dominant legume *Trifolium subterraneum*. The symbiotic fixation of nitrogen by *Rhizobium* which is the basis of this improvement may itself be limited by inorganic nutrients of which the most important so far has proved to be molybdenum. There is still scope, however, for study of the possible effects of organic substances on these microbiological processes in the soil and it is proposed to include these in the study of the fertility problems of the *Seddon* soils in due course.

In South Australia generally phosphatic fertilizers have proved to be all important for both cereal and pasture production.

Leguminous crops and pasture components are used for the maintenance and building up of nitrogen levels and in addition in certain areas micro-elements have found a place. These include, copper, zinc, manganese and molybdenum. The first three are usually used in quantities of the order of 10 lbs. of appropriate salt per acre and salts of the latter may only be needed in ounces per acre.

The micro-element which has received most attention scientifically is manganese because it has been studied the longest and because it presents special problems of availability in terms of hydrogen ion concentration and oxidation-reduction equilibrium.

The problems associated with the availability of copper and zinc are not so fully understood.

The availability and functions of molybdenum have proved to be of great interest. This element is made more available by reducing the acidity of the soil and plays an important part in symbiotic nitrogen fixation by *Rhizobium*. In other parts of Australia, however, it has been shown to be directly concerned with the nutrition of the higher plants.

In brief then, in South Australia, inorganic fertilizers have played a very important rôle in building soil fertility. They are not only concerned in the nutrition of the crop plants but may be found to play an important part in the decomposition of organic matter that may be added to the soil.

At this stage in our experience we would be inclined to regard organic manures primarily as sources of inorganic nutrients, providing both the known and unknown elements of biological importance.

ORGANIC *VERSUS* INORGANIC MANURES.

*By J. K. BASU, Soil Physicist to Government, Bombay State, Poona, and
N. D. REGE, Sr. Agricultural Officer, I/C Central Laboratory, Sholapur.*

The ultimate aim of all agricultural experimentation is to make the lands more and more productive. In India the soils in general are low in productive capacity and it has been found that the soils are deficient in many of the plant food elements such as nitrogen, phosphorus, etc. All crops take up from the soil, nitrogen, phosphate, potash, calcium and other essential elements and unless these losses are made up by some means the fertility of the soil cannot be maintained for long. It is therefore vitally important to maintain and also raise the fertility of the soil by suitable manuring practices.

It has been found by experience that nutrients such as nitrogen, phosphorus, potassium, etc., which are usually present in the plant itself are necessary to the soil. In 1840 Liebig, the German Scientist showed that mineral matter was indispensable to the growth of plants and must be supplied in sufficient quantity in the form of simple salts. The food substances added to the soil are broadly divided into two groups, i.e. manures and fertilizers. In fact this grouping is not very strict. By term 'manure' it is generally meant 'Bulky manure' which is primarily organic in nature, while fertilizer which is mainly inorganic is considered to be a concentrated substance of a particular nutrient or a mixture of nutrients. When organic manure is added to soil it supplies nutrients such as nitrogen, phosphate, etc., and in addition organic matter which goes to build up humus required for the building up of soil structure and fertility. In addition to the major elements supplied by fertilizers there are other equally important nutrients such as manganese, boron, cobalt, etc., which are known as 'rare elements' or 'trace elements' as they are required by plants in small quantities. The importance of these elements was not realized in earlier days as the fertilizers then used were carrying these elements as impurities. However, when pure fertilizers were used the plants suffered from what are known as 'deficiency' diseases. Furthermore, it has now been observed that the presence of these trace elements such as manganese and iron in the soil in addition to organic matter helps to increase the biological activity in the soil.

The plant food produced by organic manures is as good as that supplied by inorganic manures. But there is an important difference in that the organic manure is given in large quantity when compared with inorganic manures and the organic manure gets decomposed very slowly and supply the plant with food in small doses while the inorganic manure supply the necessary requirements all at once in a soluble form. In earlier days it was considered that this slow decomposition helps the plant in getting the required nutrient at different intervals and at the same time helps to maintain the fertility of the soil. Furthermore, it was felt that the plants take up only a small quantity at a time and therefore slow liberation of nutrient is beneficial to the growth of plant. This, however, is not wholly correct.

Organic manures such as farm-yard manure, green manure, etc., when incorporated into the soil not only add the nutrients such as nitrogen, etc., but the soil is enriched by the fixation of the atmospheric nitrogen. Dhar (1943) has stated that the residual effect of a manure will depend on its power to fix atmospheric nitrogen. Such materials show residual or beneficial effect to succeeding crops. He (1949) has further stated that when ammonium salts or nitrates are added to the soil, a better yield is obtained but these materials do not add any humus. In such

a case hardly any nitrogen is saved for the next crop. At Rothamsted, application of green manure like clover show that the residual effect of this manure last for about 3-4 years and that of farm-yard manure is more permanent. Further the organic matter adds humus to the soil which improves the soil texture making heavy soils lighter and lighter soils heavier.

The experiments with farm-yard manure have shown that the physical properties of the soil are improved when compared to the soil treated with artificial fertilizers. Basu and Kibe (1949) have shown that with the application of farm-yard manure, the average carbon and nitrogen contents of the soil are raised considerably, although the effect is more pronounced in the surface layers of the profiles than in the lower ones. They have further stated that the fertility of the soil is greatly enhanced by the application of the manure as judged by the increase in the level of some important dynamic fertility factors. Basu and Tagare (1942) have also shown that application of organic manure such as farm-yard manure increases the yield of sugar-cane and improves the quality of *gul*. Basu and Sirur (1943) while working on the effect of different rotations on soil structure have shown that the single value constants in Sann and Patada shevra indicate on the whole a better micro-structure than others in which bajri and fallow come next best while cotton and ground-nut are the worst.

G. Ruschman while supporting the use of organic manures has expressed that 'The increase in soil fertility which is the aim of all modern scientific and practical efforts, cannot be attained by mineral manures. Increase of crop by improving soil properties and greater returns by addition of plant food in easily available form are two different things which are often confused. Mineral manures accelerate the breaking up of humus and as such prove detrimental. Directly or indirectly all plant and animal life is made possible by the soil humus. To its increase may be systematically employed all the organic material which is at present virtually wasted.' Viswanath and Suryanarayan (1927) and McCawson (1926) have shown that certain millets, wheat and rice grown with cattle manure have better nutritive values than crops grown with artificial or chemical manures.

As regards inorganic fertilizers, it has been observed that fertilizers such as ammonium nitrate, ammonium sulphate do not enrich the soil and increase the soil fertility permanently. Most of them are lost in the form of nitrogen gas without any addition of nitrogen to the soil. At Rothamsted, experiments on wheat with fertilizers have shown that the fate of the missing 65% of the nitrogen from the fertilizer was finally traced to leaching from the soil in the form of nitrate. This effect was complete within a year and no effective residue remained for the succeeding crop. Farm-yard manure supplying, however, much more nitrogen, gave very different results. A certain amount of nitrogen remained in the soil and some of this became available for the crops in later years. The application of farm-yard manure at Rothamsted for a number of years has increased the nitrogen status in the soil from 0.12% to 0.236% in the course of 70 years. Repeated additions of ammonium sulphate or sodium nitrate did not improve the nitrogen status at all. Beneficial effects of organic manures over nitrogenous fertilizers

Yield of wheat lbs. per acre.

N. per acre.	F.Y.M.	Compost.	Night Soil.	Amm. Sulphate.
37 lbs.	1422	1303	1348	1066
73 lbs.	1526	1526	1807	1111
110 lbs.	1532	1881	1837	1241

have also been noticed at Allahabad and other places in India. Panse and his co-workers have shown that at Indore, at the high level of nitrogen applied under irrigation, nitrogen from organic manure proved more effective than ammonium sulphate.

They have further shown that response to organic nitrogen was also generally positive in the unirrigated trials. At Jalgaon responses were preponderantly negative to applications of mixed fertilizers containing ammonium sulphate, sodium nitrate, calcium cyanamide, superphosphate, etc., and this result is traced to the moisture deficiency in the soil.

Rege and Basu (1932-44) while working on sugar-cane have indicated that whenever top dressing of nitrogen in the form of organic manure such as cake is given the absence of basal dose of compost does not produce any appreciable detrimental effect even for two rotation cycles. In the cases of different proportions of sulphate of ammonia and cake its (basal dose) application can be dispensed with at the most for one cycle. On the other hand, if all nitrogenous top dressing is applied in the form of sulphate of ammonium alone, it is but essential to combine it with a basal dressing of compost for each crop of over 20,000 lbs. which is used in this experiment.

Further Rege and Basu have shown that response to manures depends also upon the soil types. While studying the response to basal application of compost and its interaction with the top dressing it has been observed that the mean response to compost is highest in F type (27%) and in D type the lowest (5%). This difference can be attributed to the nature and amount of colloids in these soil types.

The other point to be borne in mind when comparing the efficacy of organic and inorganic manures is the availability of moisture in the soil. Experiments with the inorganic fertilizers conducted at the Dry Farming Research Station Sholapur and its substations indicate that in the years of low and erratic rainfall the crops get scorched and many a time even the germination is affected. This is not the case with organic manures such as farm-yard manure, green manure or cake manure. Experiments with organic manures on Jowar (Rabi) at Sholapur have shown that the yields of Jowar could be raised considerably by these manures. At Rothamsted, it has found that farm-yard manure is most effective in dry seasons. Rainfall, however, has less effect on the action of farm-yard manure than on that of artificials, and so it happens that the superiority of farm-yard manure over artificial is most marked in dry seasons. Farm-yard manure thus has a steadying effect on yield besides its action in maintaining the fertility of the soil and minimizing the deterioration in yield often associated with continuous cropping. At the Dry Farming Research Station, Sholapur, it has been noticed that the conservation of moisture can be effectively done by the application of organic manures. Furthermore, it has been found that the microbiological activity in the soil is enhanced by its incorporation. The application of bonemeal has indicated that the level of phosphate in the soil can be conveniently raised but the effect on yield is comparatively slow. While in the case of superphosphate the results with regard to yield of jowar could be immediately seen in good rainfall years but in the year of adverse rainfall the germination of the crop—cereal as well as legume—is affected considerably by the application of superphosphate. This is not the case with bonemeal. Viswanath (1931) has pointed out that the effect of farm-yard manure on the first 36 crops was generally inferior to that of complete mineral fertilizers while average yields for the 37th to 56th crops favour the farm-yard manure treatments. Green manure was usually not favoured in the dry tracts in view of the limitation of moisture but recent experiments with the application of green manure to Rabi jowar with a suitable technique in Bombay State have indicated that even in dry tracts green manure could be beneficially used to increase the yield of jowar considerably while the ratio of C : N. can be maintained within

reasonable limits. However it can be said that barring a few experiments on certain dry crops where inorganic fertilizers are tried there are no data to give the comparative effect of organic *vs.* inorganic manures in dry tracts. While it is very difficult to say at this stage whether organic manure is superior to inorganic manure or *vice versa* to increase crop yields in different soils it has been found by experience that if the fertility of the soil is to be raised permanently it could be only done by the application of organic manure. Long range experiments with farm-yard manure carried out at different places in India have shown that though in the first few years no significant higher yields for different crops were obtained the yields thereafter have been obtained at the sustained higher level. Furthermore, the feeds obtained from application of organic manures are superior to ones obtained by application of inorganic fertilizers. According to Stewart, whilst it is of the greatest importance not to underestimate the virtues of humus and the need of bulky organic manures in general maintenance of soil fertility, it is equally important neither to overstate the case for their use nor to minimize the value of mineral supplements. Too often there is a tendency to regard manurial problems as a controversial meeting ground but to do so is to ignore the facts.'

The general evidence has shown that organic and inorganic manures have their uses and both should be regarded as complementary to each other.

Inorganic manures could be used to produce humus in indirect way as for instance, in the phosphatic manuring of legumes or green manuring crops or in ley farming with artificials. Further, suitable crop rotations are also useful in maintaining the desirable organic matter status and soil structure especially where the organic manures are not available in large quantities.

In conclusion although it may be said definitely today that in any sound scientific agriculture a balance must be maintained between the two types of manuring, emphasis should be shifted to one or the other type depending on the many diverse factors such as soil type, climate, nature of crops, cultural and rotational practices and socio-economic conditions of the locality. The foundations of such a composite system of manuring should, however, be always based on our ever-increasing knowledge obtainable through experimentation and research conducted over a long period on different soil climatic complexes.

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ORGANIC *VERSUS* INORGANIC MANURES.

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In the present discussion on Minerals *vs.* Organics the basis of the Mineral contention is chemical, and what is now known as the N.P.K. school of agriculture derives undoubtedly from the teachings of Liebig. The modern school, concerned more with what is known as 'fertility' than agriculture, on the other hand, is essentially biological. In this connection nitrogen is thought of not merely as the element N, but as *protein*; in fact the discussion is concerned rather with *humus* than with the simple element Nitrogen. We do not think of human or animal nutrition so much in terms of nitrogen but rather of different varieties of protein.

I have not yet been fortunate in meeting the second edition of Waksman's volume on Humus. In the first edition which I possess there are 500 closely printed pages of intensely interesting matter not every word of which I can claim to have read. When my own book on the Conservation of Nitrogen was published some 15 years ago I quoted the researches of Prof. Rose where he speaks of the existence of some 20 varieties of protein of nutritional value, 4 only being essential. We may look upon humus, then, to some extent as a store of protein. Waksman in fact suggests that the name humus designates the organic matter of the soil as a whole, the general implication being that humus substances are comparable to plant, animal and microbial substances.

A very important practical observation, following from this description of humus, is that of the activity of worms. Worms indeed appear to be the most important producers of humus, because they not only digest and disintegrate cellulose matter into humus but in the process they effectively aerate the soil through their active tunneling.

Here is a direct conflict between minerals and organics. The well-known mineral ammonium sulphate, on the manufacture of which some crores of rupees are being expended in India at the present time, from this point of view of the activity of worms, is actually destructive.

Whether the effect of sulphate of ammonia is due mainly to its effect upon worms or not, I have only the other day received a reprint of a paper from an old student of mine, Dr. R. D. Rege who himself did valuable research work at Rothamsted years ago and played an important part in the history of what is now so well known and is one of the special concerns of the Government of India, viz. *Compost*. Rege showed that moulds played an important part in the breaking down of carbonaceous matter. Three different species of mould were isolated in pure culture, each of which was active at comparatively high temperatures, the maximum in one case (i.e. *Acremonia*) being about 60° C.

In the paper just published (entitled: 'Soil Type of the Deccan Canal Tract—How to make the best use of them') Rege describes a good many cases in which sulphate of ammonia gives a 30% lesser yield without a basic dose of compost, and an actual 60% fall in yield when employed alone. The precise effects differ to some extent according to the type of soil made use of.

Whatever the actual meanings of these results of Rege's there can be no question of the great importance of the activity of worms since they have actually developed worm-culture farms in the U.S. from which large quantities are sent out incidentally to Holland to help to remedy the condition of the Zuider Zee flooded during war-time.

The whole question of the nitrogen requirements for fertility has greatly developed of recent years owing to the study of the '*Mycorrhizal Association*'. The

many plants which exhibit this phenomenon are actually direct consumers of protein through the finer root system. It has seemed to me important that the possible varieties of protein thus digested should be studied in greater detail, and I am glad to say there is a likelihood of this being done by Dr. S. C. Pillai and the workers associated with him at the Indian Institute of Science in connection with the activated sludge installation which has been at work there for many years. The method of investigation of separate nutritional media, it is hoped, can be similar to that employed in what has come to be known as 'Hydroponics', i.e., the aeration of the plant suspended in water together with the various nutritional elements. In this way it is hoped that considerable progress may be made in the scientific study resulting in the demonstration of the real value of Organics rather than Minerals, i.e., of biological factors in fertility rather than the old, though valuable, school of Liebig and chemicals.

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RELATIVE MERITS OF ORGANIC MANURES AND INORGANIC FERTILIZERS.

By H. D. BHOWMIK and S. P. RAYCHAUDHURI, *Indian Agricultural Research Institute, New Delhi.*

Since the time Liebig had propounded his mineral theory of plant nutrition and demonstrated that plant growth could be augmented by the application of inorganic fertilizers, a controversy had started as regards the relative values of organic manures and inorganic fertilizers in crop production. In spite of the fact that the controversy has raged for such a long time, it is unfortunate that there are not many well planned experiments which could give a definite incontrovertible answer to this question. The late Sir A. Howard, one of the indefatigable upholders of the organic school wrote—'The power to resist disease which organic farming and gardening confirm on the plant and on the animal is duly passed on to the mankind'. (Howard, 1946). Dr. E. J. Salisbury, however, stated that—'The presentation of manurial problems as a controversy concerned with organic manures *versus* mineral fertilizers is due to confusion of thought and complete failure to apprehend either the fact or the problem.'

The three important functions, among others, commonly attributed to the soil organic matter are: (1) It acts as a storehouse of plant nutrients, (2) It promotes the activity of soil micro-organisms, and (3) It improves the physico-chemical properties of the soil. It has, however, been suggested (Keen, 1946) that addition of organic matter is of doubtful value in tropical and subtropical regions owing to its rapid decomposition under temperature prevailing there. Addition of organic manures has a fertilizing value only and unlike temperate regions there is no improvement in the soil structure (Bear, 1947).

Carbon and Nitrogen contents of soils:

The amounts of organic matter in mineral soils vary widely from soil to soil and even in the same soil type the variations may be considerable according to conditions. In most soils, especially if under similar climatic conditions, (unless they have recently received a large amount of fresh plant or animal residues), there is found a more or less constant ratio of C/N of the organic matter. This ratio ranges from 8 : 1 to 18 : 1, the average being about 10 : 1. Since a rather definite ratio (1 : 1.724) exists between the organic carbon and the soil organic matter (humus), the amount of organic matter that may be maintained in any soil is contingent upon the amount of nitrogen present (Millar *et al.*, 1936).

Economy in the maintenance of Soil Organic Matter:

Every soil has more or less a definite level of organic matter and nitrogen by virtue of its equilibrium with a number of complex interacting factors including climate, natural vegetation and other environmental conditions. The method of handling of the soil such as cultivation, tillage, manurial and rotational practices may disturb this equilibrium quite considerably and consequently its productivity. Maintenance of humus at a very high level inconsistent with that permitted by the soil type, climatic and other environmental conditions would not only be difficult but also expensive. It would, therefore, be impracticable and unwise to attempt a maintenance of soil organic matter and nitrogen above a certain level consistent with crop yields that pay best (Russel, 1927).

Balanced Manuring:

While the bulky organic manures have been in use in various countries as far back as the agricultural records go, the introduction of inorganic concentrates for augmenting crop production is comparatively recent.

Violent attacks have been made from time to time on the practice of using artificial fertilizers and it has been maintained that fertilizers are harmful to the physical and chemical conditions of the soil. Experimental evidence, however, shows that the use of well-balanced fertilizers has given good results comparable to those obtained by the application of bulky organic manures. Moreover, the ratio of plant nutrients can be correctly regulated by use of artificials, whereas the amounts of such nutrients are fixed in organic manures and cannot be altered and this may result in unbalanced manuring of the crop. Injudicious use of fertilizers may on the other hand lead to the deterioration of the crop producing power of the soil. It is to be noted that organic manures also contain micronutrients needed by plants while fertilizers unless specially prepared will not contain these. On this account organic manures are often considered as 'fool proof' in the sense that one cannot go wrong with them, while with fertilizers the application must be done with certain amount of technical knowledge.

The continued use of a single inorganic plant nutrient will, in the course of time, deplete the soil of other plant nutrients and create soil conditions in which crop production is substantially lower. Where, however, suitable fertilizers have been used in correct proportions high crop yields have been obtained and there is no evidence of any soil deterioration. Continuous application of ammonium sulphate at the Woburn Experimental Station, under 50 years of continuous cropping, has resulted in almost complete failure of crops due to the development of acidity, while application of lime has been successful in making it healthy. Similar results were obtained in long term experiments in Pennsylvania, U.S.A.

Response of Crops to the Organic and Inorganic Fertilizers.

The world literature on the comparative values of organic manures and inorganic fertilizers in the maintenance of soil fertility is controversial. As a source of plant nutrients bulky organic manures (e.g. F.Y.M.) contain depending on the source, varying amounts of N, K_2O , CaO , PO_4 and other compounds including micronutrient elements. Unlike inorganic concentrates bulky organic manures may be multifold in their action and besides supplying plant food materials to the soil may have simultaneous effects on the physical, chemical and biological properties of the soil.

In the absence of proper analytical or other data for the materials used and because of omission of treatments involving the addition of equivalent amounts of nutrients in other forms in most of the experiments with bulky organic manures it is impossible to assess the relative merits of organic manures with those of artificial fertilizers. Moreover, as a source of nitrogen F.Y.M. is slower in action and less effective than equivalent amounts of nitrogen in more concentrated and readily available forms such as ammonium sulphate. This is due to the fact that the plant nutrients locked up in bulky organic manures are slowly liberated by the activity of micro-organisms. On this account it is impossible to assess the value of organic manures in a single year or short term experiments and more detailed observation of a long term nature is required. On the other hand, concentrated inorganic fertilizers may be subjected to heavy loss due to leaching, reversion or other causes whereas in the case of bulky organic manures, the constituents being slowly liberated by microbial activity are comparatively less susceptible to such loss. These facts must be taken into consideration in the interpretation of relative merits of organics and inorganics.

Results of Experiments in Foreign Countries:

Bear (1947) has presented evidence from Rothamsted Experiments started in 1852 to clearly show the value of chemical fertilizers in maintaining soil productivity and crop yields. The plot receiving 1,392 lbs. of fertilizers annually out yielded the plot receiving an annual dose of 15.7 tons of manure. This is true not only for the first 10 years and the next 40 years but for the entire 95 years average. The results are interesting and are presented below:

TABLE I.

Plot No.	3	2B	8	7	13
Annual application/acre.	None.	Manure.	Fertilizer.		
			1,392 lbs.	1,192 lbs.	99 lbs.
Period.	Yield (bu)	Yield (bu)	Yield (bu)	Yield (bu)	Yield (bu)
1852-61	15.9	34.2	36.0	34.6	32.9
1862-71	14.4	37.5	40.5	35.8	34.8
1932-42	12.7	26.1	31.0	26.9	25.7
1942-46	15.7	34.3	38.7	35.3	30.8

Bear (1947) concluded that there is no evidence whatsoever that fertilizers when correctly used, cause any deterioration of the soil or have any injurious effects on plants or earthworms or cause any deterioration in the food value of plant products.

On the other hand, the effect of 50 years of continuous cropping with either wheat or barley at Woburn Experimental Station has shown the deleterious effects of the injudicious use of sulphate of ammonia resulting in the almost total failure of the crop. Application of calcium carbonate, however, resulted in restoring the crop yields to the normal. Successful and normal barley plants could be grown on acid soils if organic manure was added. Similar results were obtained from the long term experiments in Pennsylvania, U.S.A. (quoted by Collins, 1947, p. 64) since 1882. Continued use of sulphate of ammonia brought about deterioration of yield at alarming rate but when this was used in conjunction with lime no deterioration was observed.

The importance of manure as a direct source of organic matter in general farming has been rather exaggerated. Any large and dependable increase in soil organic matter will not come from the manure itself but from the greater amounts of roots and crop residues associated with good crop growth. That this can be achieved by the judicious use of fertilizers also is shown by the results obtained at the West Virginia Experimental Station (Table II).

The content of organic matter to plough depth was increased by the use of purely mineral fertilizers from 42,800 lbs. to 60,800 lbs. This was obviously due to greater amounts of roots and other residues that were left behind on and in the soil by the nearly triple crop yields resulting from the use of fertilizers. Somewhat higher yields were obtained by the use of organic manures but it must be observed that the doses of manure applied were heavier than fertilizers.

Keen (1946) holds the view that because of the rapid decomposition of organic matter under tropical conditions, the beneficial effects of bulky organic manures lie not so much in securing a physical improvement of the soil as in supplying plant

TABLE II.

(All figures for 15 years duration calculated on acre basis).

Material applied.	Quantities applied (tons)	Amounts of			Total crop produced (lb.)	Organic matter in plough depth (lb.)
		N (lb.)	P ₂ O ₅ (lb.)	K ₂ O (lb.)		
None	Nil	Nil	Nil	Nil	40,960	42,800
(*) Fertilizers ..	5	627	627	812	117,910	60,800
Manure	190	1,900	950	1,900	139,670	73,600

nutrients that are contained in the manure. A number of experiments showed that large increases in yield were obtained by applying their ashes rather than by digging in green manure crop (Faulkner, 1934; Lewin, 1931). Doyne (1937) found that a marked increase in the carbon and nitrogen content of the soil was brought about by green manuring but the effects were transitory and within less than a year of being ploughed in, the plant residues had decomposed so effectively that there was hardly any trace left of them.

One of the important functions of organic matter in the soils is to build up a structure resistant to erosion. Organic manures do not appear to be so efficient in this respect in tropical as in temperate regions. Experiments in Uganda showed that soil structure can best be protected against erosion by growing a grass crop in the rotation (Uganda Department of Agriculture Report for 1942). Crowther (1943) has pointed out that the beneficial effects of rotation of cereal crops with roots and leys in the improvement of the soil fertility are brought about 'in ways which cannot be imitated by added organic manures'.

Results of Experiments conducted in India:

Although a fairly large number of trials have been conducted in the past with different types of organic manures in India and in major cases their values appreciated, yet in judging their relative merits with those of artificial fertilizers one would be left with confusion. In most of the experimental works attention has been concentrated mainly on F.Y.M. and the various oil cakes commonly produced in India, and on ammonium sulphate. Experiments with other soluble forms of nitrogenous fertilizers like sodium nitrate, calcium cyanamide, ammonium nitrate and urea are fewer in number. The majority of the experiments have centred around only one point, viz., the relative values of nitrogen in the manures and fertilizers without any consideration whatsoever, for the probable effects due to other food elements contained in the bulky organic manures in addition to those added in the form of inorganic fertilizers used for comparison. Moreover, proper analytical data for the soils, manures and crop are lacking. In view of these only reasonable generalizations, though not strictly accurate can be made regarding the relative merits of organic manures and inorganic fertilizers.

(a) Experiments of less than 5 years duration.

In short term experiments of less than 5 years duration the artificial fertilizers have given the highest yields and maximum response per unit of nitrogen in the majority of cases in Madras, Bombay, Bihar and Orissa, Madhya Pradesh and

* Fertilizers contain a mixture of sodium nitrate, superphosphate and sulphate of potash.

Assam. In Aduthurai and Nanjanad in Madras, in Waraseoni and Powerkhara in Madhya Pradesh and in Karimganj in Assam, mixtures of artificials and organics have proved better than either of them alone both as regards total yields as well as response per unit of nitrogen. In Koilpatti (Madras) groundnut cake plus super and sulphate of ammonia plus super were alike and were significantly better than no manure in the case of cotton, cambu and cholam.

In Berar Farm (Madhya Pradesh) groundnut cake at 20 lbs. N/acre on cotton gave 30% increased yield over no manure, whereas with sulphate of ammonia alone (20 lbs. N per acre) the yield was only 2% over no manure.

(b) Experiments of 5-10 years duration.

The general trend of these experiments is that as a source of nitrogen artificial fertilizers prove better than organics (F.Y.M. cattle manure), in earlier years, whereas the effects of the latter gradually show up only in the later periods. In Aduthurai (Madras) with nitrate and mixture of green leaf and nitrate in different proportions (to supply 20 lbs. N/acre) it has been observed that in the first two years nitrate alone gave the maximum yield of paddy per acre; in the third and fourth years nitrate and a mixture of nitrate plus green leaf were equally good, whereas in the fifth year nitrate plus green leaf proved superior to nitrate alone. Similar results were obtained in Coimbatore (Madras). In Nanjanad (Madras)—sodium nitrate gave highest yield of potato in the early years but by its constant use the yields were deteriorated due to its harmful effects. In Mangalore, Dharwar, Surat and Manjri in Madras—the inorganic forms of nitrogen (ammonium nitrate, ammonium sulphate) proved better than organic forms in the case of paddy, jowar, cotton and sugarcane respectively. In Lyallpur (Punjab)—both sulphate of ammonia and F.Y.M. were alike as sources of nitrogen on sugarcane and wheat.

In Akola (Madhya Pradesh) 9 years of experiments on cotton showed that poudrette and saltpetre were alike and gave better response (7.6 lbs. and 7.5 lbs. cotton/lb. N) per unit of nitrogen than cattle dung (3.6 lbs./lb. N). In another experiment in heavy black cotton soil, the highest response over no manure was given by F.Y.M. (10.8 lbs./lb. N) followed by saltpetre plus bone dust (9.5 lbs./lb. N) and poudrette (8.1 lbs./lb. N). In Tharsa experiments for 6 years, the responses from oil cake and ammonium sulphate were respectively 10.3 lbs. and 7.5 lbs./lb. N over no manure. Cattle dung gave a response of only 3.5 lbs. of wheat/lb. N. With sugarcane, however, for a period of 5 years til cake plus ammonium sulphate gave the highest yield followed by til cake alone. Cattle dung was least effective when applied on equal nitrogen basis. Experiments in Labhandi (Madhya Pradesh) for 7 years on irrigated wheat showed highest response in favour of poudrette (16 lbs./lb. N) followed by bone dust plus nitrate (13.7 lbs./lb. N). In Adhartal (Madhya Pradesh) different manures and fertilizers have been tried on paddy on equal nitrogen basis (20 lbs. N) on a Sehra soil (light-sandy loam) for a period of 6 years. Poudrette, cattle dung and bone dust gave significant response over no manure, the responses being respectively 30.5 lbs., 21.0 lbs. and 21.0 lbs. of paddy/lb. over no manure. Effects of fertilizers like ammonium sulphate and calcium cyanamide were non-significant (4.5 and 2.0 lbs./lb. N respectively). Experiments on irrigated wheat showed that a mixture of cattle dung, ammonium sulphate and super gave higher response per unit of nitrogen than cow dung alone.

(c) Long Term Experiments (above 10 years).

In Pratapgarh (U.P.) 16 years of experiment with paddy showed that a mixture of ammonium sulphate and bonemeal (16 lbs. N/acre) gives the highest response (26.9 lbs./lb. N) followed by cattle dung (6.8 lbs./lb. N) and neem cake (5.4 lbs./lb. N) over no manure.

In the black cotton soil Nagpur (Madhya Pradesh) 15 years of study on wheat with different fertilizers and manures has been recorded. In the first 11 years the amounts of nitrogen varied widely among different treatments. A mixture of saltpetre (240 lbs.) and bone meal (360 lbs.) gave the highest yield (117% over control) followed by saltpetre (240 lbs.) and cattle dung (160 mds.). The differences between these treatments were not significant. Manuring was, however, changed on an equal nitrogen basis (40 lbs. N/acre) during the last 4 years. Cattle dung showed the highest increase (122% over control) in yield followed by saltpetre (98% over control) and saltpetre plus bonemeal (86% over control). In Labhandi (Madhya Pradesh) experiments on irrigated paddy, poudrette showed the highest response (39.5 lbs./lb. N) followed by castor cake (36 lbs./lb. N) and bone dust plus ammonium sulphate (35.0 lbs./lb. N). In the case of unirrigated paddy poudrette was most effective and cyanamide the least.

(d) *Permanent Manurial Experiments.*

In the Permanent Manurial experiments at Pusa (Bihar) during the period 1908-30, it was found that complete fertilizer treatment gave yields which were equal and in some cases more than those obtained by applying F.Y.M. or green manure. The New Manurial series at Pusa laid out in 1932 confirm the above observation. Combination of N and P fertilizers have proved superior to N alone.

In the Permanent Manurial experiments at Coimbatore (started in 1908) it was observed that except in the case of sorghum, complete fertilizer treatment gave better results than cattle manure. In the case of sorghum, effects due to these treatments are about the same.

Carpenter (1938) observed that with tea in Assam, sulphate of ammonia is at least as efficient as, if not more than, an equivalent of organic manure in maintaining both the quality and quantity of the yields.

In the Permanent Manurial experiments at Kanpur considerable deterioration in soil has been observed in plots treated with sodium nitrate and sodium nitrate plus super. Cow dung and sheep penning treatments have preserved the soil from deterioration. At Mysore a mixture of groundnut cake and ammonium sulphate was found to be better than ammonium sulphate. Deterioration of soil has been found to occur in the long run by continued use of inorganic fertilizers unless supplemented by organic manure (Kalamkar and Sripal Singh quoted by Burns, p. 59).

OTHER EFFECTS OF ORGANIC MANURES.

Effect on Soil Structure:

Organic manures have been credited with the property of improving the soil structure. No critical experiments of a long standing nature to test this are available at present. Aldrich *et al.* (1945) have shown by laboratory methods that soil treated with different nitrogenous manures and fertilizers have their percolation rates in the following decreasing order:

Calcium Nitrate—Urea—Ammonium Sulphate+lime—Sodium Nitrate+Gypsum—Manure—Ammonium Sulphate—Sodium Nitrate.

Klintworth (1945) was unable to find any permanent improvement in the structure due to incorporation of organic matter, though he found that there was temporary effect. Keen (*loc. cit.*) however, does not believe that organic matter is responsible for any improvement in structure in tropical areas. He attributed any such effect more to the action of leys and root effects. It appears that bulky organic manures and inclusion of grasses and legumes in the rotation help the formation of structure in soils.

Effect on Nutritive Quality of Crops:

There is a belief that organic manures possess fertilizing properties in addition to those due to various plant nutrients that they contain. Convincing scientific evidence in support of the above is, however, lacking. The alleged value of auximones, vitamins and such compounds in composts, which are said to improve the quality of the crops and confer immunity from disease to plants, is by no means scientifically established. Direct tests for vitamin B₁ content in wheat with continuous manuring for over 90 years gave a 20% higher value for wheat fertilized with inorganics than with F.Y.M.

The studies of Bottomly, Mockridge and others showed that organic manures contained auxins and other plant hormones. Later vitamin B₁ as also other B group vitamins have been shown to be present in organic manures like farm-yard manure and compost. These studies probably formed the nucleus on which the organic school built one of its most imposing edifices. McCarrison and Viswanathan (1926) have claimed an increase of 15% in 'B' vitamins of crops by application of cattle-dung to the soil. These claims have been contradicted by later workers (Harrison, 1934; Leong, 1939; Tanner *et al.*, 1947). Burkholder and Gorfinkel (1948) conclude that though soils under certain conditions provide these vitamins it is not known whether plants utilize them and profit by their use.

Crowther (1949) in summarizing the present position says, 'Although interaction between plants and micro-organisms may depend in part on vitamins, hormones, and antibiotics, there is as yet no clear evidence that the traces of these substances present in animal manures and composts have any practical significance in soil fertility and crop production.'

Another contention of the organic school is that communities of people living on crops produced with organic manures are healthier than others living on crops produced on fertilizers. Critical experiments are lacking in this field. Two experiments, one in Germany and the other in America, have shown no such effect. In the Munich experiment boys 14-17 years were fed on vegetables from organic manured plots while a parallel set of boys were fed on vegetables fertilized with inorganic fertilizers. No difference was observed in a period of 4 years (Wendt, 1944). In the American Experiment quoted by Ogg (1947) a comparison was made of grass from organic manured plots with grass from water culture which was free from organics. No evidence was found to show that the inorganic fertilized grass was inferior to the other set in nutritive quality. The fact that countries using fertilizers in large quantities have a general standard of health much superior to others which depend on organic sources as plant foods, is a strong argument against any prejudice for fertilizers.

GENERAL.

The common trend of the cultivators is usually to go towards the use of organics partly due to their low cost and availability and partly due to their age old familiarity for generations connected with the belief that artificials would bring down soil fertility. In view of the present agricultural development facing the country it would not be wise to condemn the use of artificials, as it will be seen that mixture of inorganic fertilizers used in correct proportions can increase crop yields to a very high extent.

In Japan yields of rice per acre have increased by 70% during the 65 years period (1879-1942). Two factors appear to have been primarily responsible—use of commercial fertilizers and better varieties. It seems to be the general belief in Japan that the better varieties produced in recent years are better only when heavily fertilized and also that the better varieties must be grown if the full benefit of the fertilizers is to be expected. In the case of wheat also the interrelation between variety and fertilizer have been emphasized by Japanese Investigators.

This relates not only to the quantity of fertilizers used but also to the particular kind.

The bulk of the evidence on this important aspect of the problem indicates that under Indian conditions the use of a combination of organic manures and fertilizers would give the optimum results both in long and short term planning for improving soil productivity and maintaining soil fertility. Every attempt should therefore be made to conserve and utilize indigenous resources of organic manures to the fullest extent but it must not be forgotten that organic manures themselves will not be able to furnish the needs of Indian soils in entirety. The fertilizer ingredients of organic manures are not only slowly available but also not properly balanced, lacking specially in phosphate.

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• ON THE NUTRITIONAL PROCESSUS OF PLANT AS AFFECTED BY SOIL POROSITY.

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(Communicated by Prof. N. R. Dhar, F.N.I.)

All the soils are *heterogeneous*, this heterogeneity being moreover increased by the application of various fertilizers which are not evenly distributed in soil. On the other hand, a soil is a porous and *discontinuous* medium, deprived—except in some particular cases—of moving water, i.e. not retained by a more or less strong power. Thus, a conspicuous part of the vacuum is filled by the air. These conditions are very different from the conditions prevailing in plants grown on nutritive solution, as done in experiments on the mineral nutrition of the crops. It is questionable to which degree these physical properties—peculiar to the soil—affect the nutritional processus of the plant.¹

Several authors² suggested the possibility of the absorption of the elements fixed by direct exchange between the colloidal micelles of the soil absorbing complex and the pecto-cellulosic colloids forming the external membrane of the rootlets. The above hypothesis is not necessary if we consider the diffusion phenomena, not only as concerns water-soluble elements, but also for the elements fixed by adsorption, like P_2O_5 . Following experiments are significant in this regard:

A water gel of 1% gelose, in which 2 c.c. 5 of a sulpho-molybdic reagent per 100 c.c. ($pH = 5.0$) were incorporated, is prepared. Some small soil aggregates (of 1 to 2 mm. diam.) are placed on the surface and set in by a light finger pressure. After 30 min. the reduction reagent is pulverized on the surface. A blue zone appears around the granules, thus demonstrating the diffusion of P_2O_5 and measuring its intensity.

Furthermore, we directed our attention towards the diffusion of P_2O_5 of superphosphate in a discontinuous sandy medium, of various moisture contents.³ In this purpose, columns of fine sand were used, of 6, 9 and 12% moisture content, this last figure representing the retention capacity over vacuum. The superphosphate was placed either at the lower or at the upper part of the columns, and samples were taken after 15 days. Thus it was observed that diffusion, very slow at low moisture contents, increases with water contact up to retention capacity. In clay soils the ionic diffusion is still much more restrained.

We also investigated the variations in the concentration of the soil solution, when the amount of P_2O_5 applied as superphosphate increases. The results obtained indicate that, in most soils having a high fixing power, in order to raise the concentration up to 1 mg. per litre corresponding to the maximum effect in a liquid solution, a much larger application of fertilizers than that effectively required for the maximum field yield appears to be necessary.

To sum up the above considerations support the following views:

- (1) The concentration in a given element of the solutions present in the soil is not uniform, especially after a fertilizer application. This heterogeneity is more marked with granular fertilizers or in the case

¹ The low ionic migration in the suspensions of clay has been observed by R. Schofield, (*Discussions of the Faraday Soc.*, 1948? No. 3).

² Jenny, *Soil Sci.*, 1939, t. XLVII, p. 257.

³ *C. R. Acad. Sci.*, 1950, t. 230, p. 595-598.

of placement, chiefly when the moisture decreases below the retention capacity of the soil. The laboratory methods, in which a liquid reagent is used, are destroying the structure of the soil in situ. These methods determine the supply of an element in a more or less labile form. Now the plant must be able to utilize in a different way this amount, according to its topographical distribution in the whole mass and the water contents of the medium. Rainfall, as practice shows, has a marked influence both on the utilization of the fertilizing elements, as ascertained through plant analysis, and on the efficiency of mineral manures. Homogeneity in the soil solution can only be assured when the moisture tends towards saturation and when a speedy diffusion of the dissolved materials occurs in strongly leached, weakly buffered soils. These facts explain that the results obtained through analysis don't have but a probability value, and that a discordance can be observed between the laboratory results and the response of crops to fertilizer. This discrepancy is not related to the constitution of the reagent used but to the principle itself of the method. Thus all the efforts made in view of discovering a reagent having an absolute value will remain fruitless.

- (2) A narrow and permanent correlation between the estimation of the soil reserves and the plant uptake during the growth period cannot be expected. These two notions must be distinguished. The first one has a static and permanent character, whilst the second one depends on the climatic conditions, especially the moisture of the medium, which in laboratory experiments is accurately maintained at a high and constant level. The requirement in a fertilizing element, as stated by soil analysis, has a practical value according to the probability degree resulting from the comparison of the analytical data with the information obtained through a long field practice. Nothing more may be expected. The plant analysis shows us, indeed, the nutrition in the same soil to vary considerably in course of the years; thus an optimum cannot be precisely determined. As regards the discordances sometimes observed between the two groups of methods, they always disappear in the extreme cases.

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• HUGE WASTAGE OF ORGANIC MANURE RESOURCES IN INDIA.

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(Communicated by Prof. N. R. Dhar, F.N.I.)

The ecological aspects of crop production are apt to be overlooked in the modern craze for exploitation of land and immediate profits. In any system of long term planning for agricultural development, due consideration must be given to the fact that plants are complex living organisms, which have been evolved to suit the substratum of a living soil, containing myriads of micro-organisms, which are as much living as the plants or animals themselves. In fact the links, man - animals - plants - microbes - viruses and enzymes, form an inter-connected series in the phenomenon of vital energy manifestation, which has been evolved to be in tune with the broader ecological conditions existing in this planet since it was created. Any fundamental alteration in any one of the above links is sure to affect the strength and vitality of the other links in the chain. The method of feeding the microbes and plants of the soil is an important matter which in turn affects the food of animals and of man, and hence their physical and mental make up.

It is against the above background that we have to consider the present question of 'Organic *vs.* Inorganic Manures in relation to land improvement and crop production'.

Through long centuries and in fact through thousands of years, ever since man changed over from his nomadic life and settled down to agriculture, we have been adopting a method of cultivation of crops based on the use of organic manures, and we have got the cumulative experience of the above long period to show that man's best physical and mental development could be secured by the consumption of crops grown in the above manner.

But very recently, namely during the last one hundred years, scientists have found out that plant growth can be stimulated by the addition of chemicals containing nitrogen, phosphoric acid and potash. Davy in the beginning of the last century started the idea that the plant was a chemical phenomenon whose growth can be controlled with the help of chemicals. Liebig followed this up with his chemical theory of plant nutrition which laid the foundation for the fertilizer industry, which during the last 100 years has grown up to enormous proportions. The idea was first taken up in England by Sir John Lawes who started a flourishing fertilizer business and established the Rothamsted Experimental Station.

A great deal of intensive propaganda has been carried out by the fertilizer industry to persuade farmers of the 'immediate' profits that can be obtained by dumping chemicals on their land; and their propaganda has been helped to a great extent by the wave of industrialization that is coming over agriculture all over the world with its attendant evils of reckless exploitation, craze for immediate profits and blindness to the results of tomorrow.

Even Liebig, the father of the Chemical Theory of Plant Nutrition, realized the limitations of the chemical hypothesis when he said: 'There is but one manure, which permanently keeps up the fertility of the land and that is farmyard manure; and when the necessities of the times compel the farmer to search for means to replace this invaluable manure in all its effects, this can only be rationally done with any prospect of success if we replace all its constituents'. Again, Sir John Lawes, the founder of the Fertilizer Industry in England, declared, 'Sometimes it has been maintained that a soil is a laboratory. . . . But not only the facts ascertained in our own and other investigations but the history of agriculture through the world so

far as it is known, clearly show that a fertile soil is one which has accumulated with it the residue of long periods of previous vegetation and it becomes infertile as this residue is exhausted.'

The effects of the indiscriminate dumping of chemicals on to land were first seen in the U.S.A. which was blessed with about 1,500 million acres of the richest land in the world, when it was occupied by the settlers from Europe. During the last 100 years, reckless exploitation of the land has been going on so rapidly that it is now estimated that about one-third of the land has become infertile and that another one-third has become 'marginal'. The Americans have not felt so badly the results of their indiscreet treatment of their land due to the fact that their population is less than one half of that of the Indian Union and their fertile area is still double India's. But public alarm and soil-consciousness in the U.S.A. has been aroused sufficiently in the matter and the Government have formed a Soil Conservation Service, for pooling together Governmental and private resources in a national effort to save the remaining land from destruction and to reclaim the 'marginal lands'; but it remains to be seen how far the craze now prevalent in the U.S.A. to industrialize agriculture and to mine their lands would permit the private owners to preserve their lands on a basis of permanent fertility.

Scientists know that the capacity of a soil to erode is closely related to the structure of the soil, which in turn is conditioned by the amount of humus present therein and the activity of micro-organisms. The soils in America were originally rich in humus and in fertility, but due to reckless exploitation, they lost humus rapidly and became in the end vast dust bowls—vast sheets of floating sand. In India also the problem of expanding deserts and soil erosion is standing at the doors of the fertile Gangetic valley and is advancing eastwards at the rate of a mile per year.

The only way to save our lands from gradual conversion into deserts is to adopt sound methods of agriculture based on the use of Organic Manures and absence of stimulants.

The work of McCarrison and Viswa Nath in India has shown that food grown on a fertile soil (organically manured) has higher nutritive value than food grown on poor land or with chemicals. The effect of different chemicals on the microbial population of the soil has not yet been studied in detail, but it is known that they adversely act on the earth-worm population, which under conditions of organic husbandry help to aerate and enrich the soil considerably.

Probably, the only country which has shown, by example, its capacity to maintain its soils at a high level of fertility for the last 3,000 or 4,000 years is China which possesses almost a similar density of population as India. China has been able to produce enough food for all its 500 millions without the use of chemical fertilizers and at the same time the fertility of their soils is remarkably high, compared to that in India. The yield of rice in China is more than double that in India; and these high yields have been maintained for centuries together without any soil deterioration. The secret of the continued success of Chinese agriculture during thousands of years is due to the fact that they have taken extraordinary pains to collect and apply to their land very large quantities of organic manure prepared from the refuse materials available in their towns, villages and farms. F. H. King, in his well-known book: 'Farmers of Forty Centuries', gives a striking testimony to the agriculture of China and the adjoining countries of Korea and Japan, when he says, 'One of the most remarkable agricultural practices adopted by any civilized people is the centuries long and wellnigh universal conservation of all human waste in China, Korea and Japan, and its utilization in the maintenance of soil fertility and in the production of food. On the basis of the data of Wolff, Kellner and Carpenter, or of Hall, the people of the United States and of Europe are pouring into the sea, lakes or rivers, and into the underground waters, from 5,794,300 to 12,000,000 pounds of nitrogen, 1,881,900 to 4,151,000 pounds of potassium, and

777,200 to 3,057,600 pounds of phosphorus per million of adult population annually, and this waste we esteem one of the great achievements of our civilization. In the Far East, for more than thirty centuries, these enormous wastes have been religiously saved, and today the 400 millions of adult population send back to their fields annually 150,000 tons of phosphorus, 376,000 tons of potassium, and 1,158,000 tons of nitrogen comprised in a gross weight exceeding 182,000,000 tons. They are gathered from every home, alike in the country, villages and in great cities like Hankow-Wuchang-Hanyang with their 1,770,000 people swarming on a land area delimited by a radius of 4 miles.

'Man is most extravagant accelerator of waste the world has ever endured. His withering blight has fallen upon every living thing within his reach, himself not excepted; and his besom of destruction in the uncontrolled hands of a generation has swept into the sea soil-fertility which only centuries of life could accumulate—fertility which is the substratum of all that is living.'

Mr. Chaman Lal in his recent book on 'Cottage Industries in Japan' gives the following anecdote which reveals clearly the high value which the Japanese attach to night-soil. He says:

'Japan is the most modern country in Asia, yet she faithfully clings to the old practice of preserving the night-soil in the homes, in towns, in the fields and in the villages. When I established a home in Tokyo I wrote to the Municipality to send me a sweeper twice daily to clean the toilet. This request shocked the officer-in-charge who wrote back saying that as a special favour he was prepared to send me a sweeper every tenth day although regular collection of night-soil from homes was made only once a month. Every home is provided with a disinfectant which is used twice daily to deodorize and the night-soil is preserved in a deep pit until the sweeper comes on his round with a clean wooden container (not the open buckets as used in India). The containers are loaded on carts and sometimes on animals. They used to be carried by sweepers too, but the practice has been abandoned. How I wish the sweepers in India could be provided with the same facilities. I asked an official in Tokyo, "Why don't you flush the entire night-soil out into the sea?" He retorted: "That would be waste. We throw nothing away. It is worth much money." The peasant realizes the value of night-soil so much so that he invites passengers on the roads to use his field lavatory for his benefit. Notice boards on the roadside invite passers-by for profit to the owner of the field. Manure is like gold to the peasant.'

Even though India possesses more cattle per acre under cultivation than Japan, she is applying less than a ton of organic manure per acre, as compared to about 4 to 5 tons per acre applied in Japan.

TABLE I.
Comparison of Japan and India in Manure Production.

Particulars.	Japan.	India.
1. Number of cattle and horses	4.5 millions ..	150 millions.
2. Area under cultivation	14.44 million acres.	200 million acres.
3. Cattle (including horses) per acre of cultivated area	0.32 ..	0.75
4. Total quantity of cattle shed and rural compost prepared	62.8 million tons ..	150 million tons.
5. Quantity of manure per acre of cultivated area	4.40 tons ..	0.75 tons.
6. Quantity of plant nutrients added in the manure:		
Nitrogen	52.3 lb. per acre ..	8 lb. per acre.
P ₂ O ₅	20.4 lb. per acre ..	3 lb. per acre.
K ₂ O	44.8 lb. per acre ..	10 lb. per acre.

India, of course, has vast potentialities for organic manure preparation from her indigenous resources, but due to lack of proper organization and the indifference and in some cases active opposition of the vested interests during the 200 years of British rule, not even 10% of her manurial resources are at present being utilized as shown by the data in the table given below:

TABLE II.
Potential supplies of Manure in India.

Particulars.	Dry matter.	Organic matter.	Nitrogen.	P ₂ O ₅	K ₂ O
POTENTIAL SUPPLIES PER YEAR:	(All figures in millions of tons per acre.)				
(A) Cattle shed refuse from 150 million cattle (produced in night time while the animals are tied up in the cattle sheds).					
Dung	144.6	115.7	1.808	0.723	1.085
Urine	33.8	26.5	3.616	0.072	2.531
Wasted fodder and litter at 1 lb. per head per day ..	20.0	16.0	0.100	0.060	0.160
(B) Farm wastes (80 million tons of weeds crop residues, sugar-cane trash, cotton stalks, jowar, stubble, etc.) ..	60.0	50.0	0.240	0.140	0.420
(C) Human wastes of 350 millions population:					
Night-soil	4.80	4.35	0.240	0.192	0.096
Urine	6.00	2.40	0.960	0.144	0.216
Town and village refuse at 1 lb. per head per day ..	50.00	25.00	0.250	0.250	0.500
(D) Forest litter available for manure preparation, water hyacinth and other sources 50 million tons per year ..	20.00	16.00	0.200	0.100	0.200
TOTAL MANURIAL RESOURCES IN RURAL AREAS ..	339.20	255.95	7.414	1.681	5.208
RECOVERED AND USED AS MANURE AT PRESENT:					
(A) 150 million tons of manure prepared in villages—(Moisture 50%, Nitrogen 0.4%, P ₂ O ₅ , 0.2% and K ₂ O, 0.6%) ..	75.0	18.00	0.600	0.300	0.900
(B) 10 million tons of compost prepared in towns and on farms ..	5.00	1.20	0.050	0.030	0.060
TOTAL QUANTITY RECOVERED	80.00	19.20	0.650	0.330	0.960
Percentage efficiency of recovery	23.60	7.5	8.8	19.6	18.5

India is at present losing every year about 237 million tons of organic matter 6.76 million tons of nitrogen, 1.35 million tons of phosphoric acid and 4.25 million tons of potash. Even if one half of the above losses could be saved and applied to land as manure, we can increase our food production by about 20 million tons, which would be more than sufficient to make the country self-contained in the matter of foodstuffs for another 10 years to come.

The main loss of organic matter and of nitrogen occurs under the following heads:

(a) *Cow dung burnt for fuel*: This is estimated at about 300 million tons fresh weight, containing about 50 million tons of organic matter, 0.9 million tons of nitrogen, 0.36 million tons of phosphoric acid and 0.5 million tons of potash. The seriousness of this loss was pointed out as long ago as 1893 by Dr. J. A. Voelcker in his Report on the 'Improvement of Indian Agriculture' presented to the Government of India, but nothing substantial has been done and the position has further deteriorated since then. Quite recently, Government of India have started a drive for tree planting all over the country and a Vana Mahotsava Week is being celebrated from July 1st to 8th. The drive, however, will have to be intensified and a proper plan of re-afforestation in villages will have to be executed on a large scale if substantial results are to be achieved.

(b) *Loss of cattle urine in the night-time by soaking into the cattle shed floor while the animals are tied up in the villages*. Even if one half of the urine can be saved it would amount to the big figure of nearly one million tons of nitrogen. This cattle urine is a very good starter for decomposing farm litter and should be conserved by spreading litter or earth under the cattle in the zones where the urine soaks into the ground.

(c) *Loss of night-soil and urine in towns and villages*: The loss under this head amounts to about 12 lakhs tons of nitrogen, 3.30 lakh tons of phosphoric acid and 3 lakh tons of potash. At present a small scheme is working for composting town refuse and night-soil, under which about 15 lakh tons of manure are being prepared, at about 1,000 Municipal centres, but there is potential scope for increasing the production to a level of 100 lakh tons by utilizing the refuse available from all the 5,000 urban centres.

Then there are nearly $5\frac{1}{2}$ lakhs of villages containing a rural population of nearly 250 millions. In China, the human excreta are conserved to the utmost extent both in the towns and in the villages. In India also we should introduce the Wardha System of Trench Latrines into all the villages. By doing so we could prepare an extra 250 lakh tons of good manure.

(d) In addition to the above major items, there are others in which substantial losses of organic matter and nitrogen occur, e.g., in the burning of sugar-cane trash on sugar-cane estates. There are about $3\frac{1}{2}$ million acres under cane in India and the total production of trash is estimated at about 10 million tons per year. This could be converted into useful compost manure on the fields themselves. Again, nearly 50,000 acres are infested with water hyacinth in West Bengal and there are also considerable areas so infested in North Bihar, Orissa and parts of U.P., Travancore and Hyderabad State. Water hyacinth, if collected and composted, forms excellent manure containing about 2% of nitrogen. Then again, we have about 1,71,000 sq. miles (about 100 million acres) under forests in India which contain heavy accumulation of well decomposed humus. Without causing any damage to the natural regeneration or fertility of the soils, it will be possible to remove say 10 tons per acre once in 10 years from a totation of forest blocks. This would yield us a supply of nearly 100 million tons of good quality manure every year.

The above brief review will show that we have enormous resources of good quality organic manure in the country and it is an economic loss of the order of nearly 1,000 crores of Rupees per year if we allow the good organic manure to either soak into the ground or gasify into the air and at the same time we spend crores of Rupees of our limited wealth in order to import fertilizers from abroad.

The use of organic manures has been tested through thousands of years experience as a safe method of maintaining soil fertility and obtaining high yields, and we have with us unused resources for preparing nearly 300 to 400 million tons more of such organic manure, which will provide us enough food to meet our

requirements for some decades to come. Instead of treading the uncertain path of spoiling our soils by indiscriminate dumping of chemicals which would only stimulate them and goad them temporarily, why not feed the soils in a healthy manner and obtain food of the best quality which would sustain and invigorate the people in their onward march to take their rightful place as a healthy and virile nation in the *World Community* of Nations.

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WHY ORGANIC MANURES ARE BETTER THAN CHEMICAL FERTILIZERS.

By J. I. RODALE, *Emmaus, Pennsylvania.*

(Communicated by Prof. N. R. Dhar, F.N.I.).

The purpose of this statement is to present data to show that there is a need for a scientific re-evaluation of the use of Chemical fertilizers and poisonous insecticides in our agriculture. In my opinion sufficient scientific data already exists to show that the extended organic method is far superior to the present general practice with respect to fertilizer usage, from not only the human health standpoint but from the point of view of preventing soil erosion and giving higher yields at a lower cost.

HISTORY OF THE ORGANIC METHOD.

There is a tendency to say that the organic method is as old as history and was practised by the oldest civilizations. This is not true as evidenced by the downfall of those civilizations. It is possible that with the practice of the extended organic method on a widespread scale in any civilization, that civilization will be able to persevere indefinitely and not go the way of Babylonia and Rome. These old civilizations countenanced the burning of manure as a fuel and stood idly by while the most rudimentary principles of basic agriculture were violated. The world has never seen, except in a few isolated cases, the practice of a thorough organic method, and with such a practice there is hope of building a civilization such as has never before been seen, for not only does physical health come from our food through the fertility of the soil in which it grows, but also our minds and characters are nourished and nurtured through that very soil. The people can only be a reflection of the soil which they culture. Poor soil—poor people. Mediocre soil—mediocre mentality of the people. Science can quickly prove this.

The founder of the organic farming movement is Sir Albert Howard who in 1940 wrote *An Agricultural Testament*, which was published by the Oxford University Press and has since gone into many printings. This book states in no uncertain terms that the use of chemical fertilizers are dangerous to the health of people, animals and the soil. It describes how oxen in India that were fed on organically produced food could rub noses with oxen that were eating ordinary food and that had hoof-and-mouth disease and did not contract the disease even though they were not inoculated against it. Sir Albert was a British Government agricultural scientist of the highest standing. He was knighted for his contributions to agriculture. This book is a *must* in an investigation of this kind and represents the experience of more than thirty years with the organic method.

THE EXTENDED ORGANIC METHOD.

The organic method is still in a process of improvement and evolution. Originally, ten years ago, it consisted merely of the making of compost from organic matter such as manure, leaves, weeds, etc. Then a source of phosphate was added in the form of phosphate rock ground up fine. Recently we have added the use of potash rocks of various kinds, usually granites. Potash is also used in the form of greensand. These give their nutrients to the soil without the acids or the high solubilities of the chemical forms of these elements. In the organic method we

also use lime and slag from steel furnace processes. There is already available manufactured fertilizers which contain organic matter and ground rocks mixed to give controlled combinations. A thriving new industry is gradually being built up to serve the organic farmer and gardener, which has shown an interesting growth in the last two years. The chemical fertilizer industry should not disdain this market, for it may eventually be like the story of the tortoise and the hare or the railroad and the stage-coach. Once a person has started with the organic method it is rare to find him change back to chemicals.

Originally, when the organic farmer was dependent only on the making of compost, it was quite difficult to practice the organic method, but now with the various rock fertilizers the need for organic matter is lessened and the method is becoming quite practical. Another thing to bear in mind in regard to the practicality of the method is that originally all the organic matter had to be composted first before being applied to the land. We now apply the raw organic matter direct to the land in places where crops will be planted later. This is not only labour-saving but conserves more of the nutrients of the organic matter. This is in accordance with the researches of Dr. N. R. Dhar, Head of the Chemistry Dept. of Allahabad University.

THE HEALTH ASPECT.

I should like to present a piece of research that was done by Dr. Ehrenfreid E. Pfeiffer at his laboratory at Threefold Farms, Spring Valley, New York, in 1948-49, which was financed by The Soil and Health Foundation of which I am the President. Dr. Pfeiffer was granted the honorary M.D. degree by Hahnemann College of Philadelphia for his work in diagnosing disease by means of crystallization of the blood. In this experiment two groups of mice were fed—the one on food raised with chemical fertilizers and the other with organic fertilizers, which proved that the group of mice that was fed with organically produced food was much healthier than that which was fed with food raised with chemical fertilizers. The results were recorded in Bulletin 2, dated November, 1949, of the Soil and Health Foundation. It showed, for example, that in a strain of mice that was chosen for its susceptibility to cancer, the survival rate was 64% in the case of the organically fed mice and only 35% in the case of the mice fed with chemically fertilized food. In connection with deaths from fighting—the organically fed group suffered 15% of deaths while the chemically fed mice killed each other off at the rate of 21%. In examining the mice themselves an interesting thing could be observed.

After the first stage of this experiment was completed, the mice were subjected to a carcinogenic or cancer-causing chemical, painted on the skins of both groups. In the chemically fed group 71% of them became cancerous. In the organically fed group, only 45% came down with the disease.

That chemical fertilizers could be detrimental to human health was shown by a professor of Cornell University, a noted soil scientist, the late Dr. J. K. Wilson. In an article in the January, 1949, issue of *The Agronomy Journal*, entitled 'Nitrate in Foods and its Relation to Health', Dr. Wilson said: 'Leafy vegetables, frozen foods, and prepared baby foods were analysed for their content of nitrate. From the findings it is suggested that the nitrate in such foods may contribute to hemoglobinemia found in infants and may produce certain toxic, if not lethal conditions in adults. The high content of nitrate in the foods may be attributed in many instances to the application of nitrogenous fertilizers, especially nitrate of soda, to the growing of crops.'

An experiment was carried out by M. J. Rowlands and Barbara Wilkinson, two university research workers, who reported their findings in the *Biochemical Journal*, Volume 24, No. 1, 1930. In it they said: 'It was decided to try the effect of artificial manure (chemical fertilizers) *versus* dung. A crop of clover and grass was grown, one-half fertilized with dung, the other half with chemical fertilizers

including basic slag, kainit and sulphate of ammonia. Then rats were tested by feeding them the product of these fields....The rats were divided into two lots; one lot was put on a deficiency diet to which was added 20% of the "dung" seed, the other on a deficiency diet with 20% of the "artificial" seed....The rats on the "dung" seed showed good growth or a slightly subnormal growth....The rats on the "artificial" seeds all grew very poorly, not one giving normal growth....It can be seen that the former have gained nearly twice as much as the latter....The rats on the "artificial" seed were in poor condition; in some the hair was falling out.'

Sir Robert McCarrison, the great English research physician, in 1926, in experiments with grains at Madras, India, discovered the same thing. He found that grain, if grown organically, contained more vitamins. For more details see the *Journal of Indian Medical Research*, Vol. 14: 351, 1926.

In Chapter 12 of *Bio-Dynamic Farming and Gardening* (Anthroposophic Press) the author, Dr. Ehrenfried Pfeiffer, describes an experiment with chickens. The organically fed chickens were stronger, laid more eggs and produced a more hatchable egg. In the chemically fed group only 35% of the eggs hatched. In the group where the chickens were fed on feeds grown organically, hatchability was 68%.

In the same book Dr. Pfeiffer gives in great detail, pages 185 to 190, a description of experiments carried out with turkeys in feeding with chemically fertilized feed as against feed produced with stable manure. The article summarizing his results, was entitled 'The Biological Value of the Products of Soil Fertilized with Animal or with Chemical Fertilizer', and was published in the *Proceedings of the R. Accademia Nazionale dei Lincei*, Mathematical, natural scientific division, Vol. XIII, series 6, I, Rome, February, 1931. The results were spectacular. The turkeys fed with food grown with stable manure showed a smaller number of cases of sickness, a shorter duration of it and a far smaller number of deaths. He summarizes: 'This means that the seeds, and still more the leaves of plants fertilized with stable manure have the peculiarity, when used as food for these animals, of increasing their capacity for resisting disease to a greater degree than the corresponding seeds and leaves of mineral-fertilized plants. The former have thus a higher biological value than the latter.' The stable manure also produced higher yields in the plants.

In Dr. Pfeiffer's book mentioned above, pages 190-191, the author mentions three German physicians, Schulz, Reinhardt and Kalkhof, who wrote articles in German medical magazines giving their experiences in effecting cures of patients with the use of organically produced bread and other products. They cured a series of metabolic disturbances. They found it to be especially effective with weak and backward children, and to have a definite influence on the functioning of the stomach and intestines. They have thus cured, without medications, cases with marked stomach troubles and sluggish intestinal activity.

There is a host of scientific information available in the literature to prove that the use of organic matter in the soil makes for healthy plants. I will quote a statement by Dr. Selman A. Waksman, the discoverer of streptomycin, from his book, *Humus* (p. 409): 'Plant deficiency diseases are usually less severe in soils well supplied with organic matter not only because of the increased vigor of the plants but also because of antagonistic effects of the various soil micro-organisms which become more active in the presence of an abundance of organic matter'. At the Connecticut Agricultural Experiment Station, this was confirmed in experiments with fusarium rot of squash seeds (Bulletin 500, Nov., 1946, *Physiology of Fusarium Foot Rot of Squash*).

If space permitted I could give data from ten or more physicians who have written upon the effects of chemical fertilizers and human health. I will mention one—James Asa Shields, M.D., Professor of Neuropsychiatry of the Medical College

of Virginia, who at a meeting of over 1,000 physicians at Miami, Florida, on Nov. 4, 1946, said, 'Thus we see that multiple sclerosis, depletion of soil, and the introduction of inorganic chemicals as a treatment for the soil were all introduced to man between the years 1836 and 1840'.

In spite of all this evidence much of which has been available for many years, many agricultural scientists who are at the head of Departments in large American Agricultural institutions have pronounced in speeches and in articles that there is no evidence that the organic method of producing food gives people better health.

WHY THE ORGANIC METHOD IS DESIRABLE.

In my book *Pay Dirt*, Chapter 9, I have listed 36 reasons why organic farming is superior to farming with chemical fertilizers and I am submitting that chapter as Exhibit L. Here, however, I am only going to list the 36 of them, as follows:

- (1) The general fertility level of the farm or garden is greatly improved by the organic method.
- (2) This method improves the soil's mechanical structure which includes its granulation, tilth and increase of pore spaces.
- (3) It makes of ease of cultivation.
- (4) It eliminates valuable waiting time. The farmer can get back on the soil quicker after a rain.
- (5) It increases the soil's water-holding capacity.
- (6) It prevents soil erosion and reduces flood hazards.
- (7) It prevents hardening of the surface soil by driving rains.
- (8) The earthworm multiplies greatly, because organic matter is its natural food.
- (9) It multiplies the microbial population of the soil.
- (10) Land can safely be plowed more deeply.
- (11) Hard-pans will not form.
- (12) There is no danger of a plow-sole.
- (13) Heavy machinery does not compact the soil as much.
- (14) The soil has much better aeration.
- (15) Soil made darker by humus absorbs heat more quickly and more effectively.
- (16) Dry weather advantages. Under drought conditions an organic soil will fare better due to its stored up water.
- (17) It may actually improve rain conditions.
- (18) It transpires less water through the leaves.
- (19) The manure produced from cattle fed on an organically operated soil improves in quality from year to year.
- (20) Making compost where small farmers decide to do it, increases the available manure by 300 per cent.
- (21) Compost heaps preserve all the food elements in the manure.
- (22) Compost have a residual effect.)
- (23) When following the organic system your grounds look neater.
- (24) Weeds can be cultivated more easily out of an organic soil.
- (25) Compost is a 'safer' material than just ordinary stable manure.
- (26) Compost kills out weed seeds.
- (27) There is less risk of crop failure.
- (28) There is very little plant disease.
- (29) The insect menace is reduced to a minimum.
- (30) Few, if any, poison sprays are needed.
- (31) No chemical treatments are needed for seeds.
- (32) It builds health.
- (33) Farm animals fed on organic produced feeds are healthier.

- (34) Foods raised organically taste better.
- (35) The general quality of the crop is much higher.
- (36) Humus seems to counteract the effects of poisons in the soil.

WHY CHEMICALS ARE HARMFUL ?

Usually a typical chemical fertilizer contains a nutrient that the plant can use, but it also carries elements that the plant cannot take up in appreciable amounts. The result is that these other substances remain in the soil and cause trouble. A case in example is nitrate of soda. The plant uses much of the nitrate but not much of the soda which remains in the soil and is known to be a hardening agent. This sodium actually combines with carbon to become carbonate of soda which is washing soda. Some soils become almost as hard as concrete because of this. Then when it rains the water cannot penetrate and washes off the soil, taking some of the top-soil as erosion along with it. Another bad feature about the soda in nitrate of soda is that in many cases the plant takes up more soda than is good for it, and it has the effect of driving out other important nutrients. Similarly, other chemical fertilizers carry substances which remain as dangerous residues in the soil.

ROCKS AS FERTILIZER.

If any one thing can come out of this investigation it should be the development of a new consciousness in agriculture in regard to our attitude toward ground up rocks as a fertilizer, because India has billions of dollars worth of this resource which is now going begging. In a paper entitled *Native Rocks as a Fertilizer* written by Dr. W. D. Keller, Professor of Geology of the University of Missouri, which appeared in the April, 1950, issue of the *Organic Farmer* we have an amazing document, for here is a scientist, who is closely associated with Professor William Albrecht of the same university, and who unequivocally attacks the use of chemical fertilizers. He wrote an article, 'Native Rocks and Minerals as Fertilizers', in *Scientific Monthly*, February, 1948, in which he says: 'The serious defect of a highly soluble, concentrated fertilizer is the powerful mass-action effect that it exerts to overstock with a few elements the humus and clay colloids from which the plants accept their nutrients, thereby suppressing, or blotting out entirely (for practical purposes), the availability of other elements also sorely needed by plants for optimum growth. The rich solutions from the soluble fertilizer convert the "nutrient jobber" colloids into a relatively homogeneous, undiversified system, which forces on to the plants an excess of a few elements to the exclusion of others. By its overconcentration in some constituents such a fertilizer creates nutrient deficiencies in others—despite its purpose to correct deficiencies.'

In an article I wrote in the Feb., 1949, issue of *Organic Gardening* entitled Phosphate Rock, I give much data to show the practicability of using ground up phosphate rock instead of superphosphate. It shows that in the State of Illinois very little of the superphosphate is used by farmers. For example in 1947 that State used about 48,000 tons of superphosphate against 707,000 tons of the ground up phosphate rock. The answer of some agriculturists is that the soil is different in each state and that phosphate rock cannot be used where the soil is too alkaline. But it is a known fact that where there is sufficient organic matter the phosphate in the rock becomes available through the organic acids of the decaying organic matter even under alkaline conditions. Phosphate rock alone is therefore not sufficient in good organiculture practice, and that is the advantage of the organic method which places such an important stress on the obtaining of outside organic matter, that is, residues of organic matter which are to be found outside of a farmer's own place, matter which today is dumped or burned. It exerts beneficial effects on minerals in the soil.

Along with phosphate rock there is available billions of tons of various kinds of rocks which contain potash. A bulletin issued recently by the Connecticut Agricultural Experiment Station entitled *The Potash in Granite is Available* describes a three year experiment in the growing of tobacco using granite rock as the potash source against the chemical form which proved that the potash in the rock *was* available for the needs of the growing crop. The tobacco grown with the rock had a better smoking aroma and the ash was superior, while the yields were not any lower than the chemically fertilized tobacco. Had organic matter been used as is done in the organic method the yields no doubt would have been much higher.

The agricultural scientists must turn about in their attitude toward the rock fertilizers which have been absolutely ignored by them. Experiments must be begun on an extensive scale. They must not close their minds academically to it simply because their text-books state that the nutrients in rocks are not available. The text-books will have to be altered. We are living in an era of change. For India billions of dollars can be saved if that country uses ground rocks instead of chemical fertilizers.

Trace Elements.

One of the most astounding things about the controversy between the organiculturists and the chemicalists is the fact that the latter in their writings and in their experimentings have shown and proved conclusively that by means of the organic matter in the soil the trace mineral elements become available to growing plants. I do not have to use up any time to describe the tremendous importance of making these trace minerals available. Much of the disease in plants is due to their lack. It is through the organic matter in the soil that the trace elements are usable by the plant. Truog and Berger of the University of Wisconsin, have recently stated that after testing thirty-four virgin and forty-eight cultivated soils, the organic matter in the soil made boron available to plants. Soils with a high lime content and soils depleted of organic matter, they said, were found to be low in boron that the plants could use. It is not enough to have boron in the soil. It must be available. Also, an excess of potassium makes the severity of boron deficiency more pronounced. The last statement is important because it shows how in the use of potash that is obtained from the too highly soluble chemical fertilizers an oversupply can easily be achieved, which then acts as a depressant on the boron in the soil.

HOW DOES THE ORGANIC METHOD COMPARE TO THE CHEMICAL METHOD AS FAR AS YIELDS ARE CONCERNED?

In an editorial I wrote in *Organic Gardening* of December, 1950, entitled 'Do Chemical Fertilisers Give Higher Yields?' I gave data to show that the greatest yields come where there is sufficient organic matter in the soil, and here again damaging evidence is given—pronouncements made by our very critics—that organic matter is at the bottom of high yields. A statement is included by Wheeler McMillen, Editor of the *Farm Journal*, who shows that there has not been an increase in farm yields in the last fifty years. This in spite of the heavily increasing use of chemical fertilizers. That chemical fertilizers give higher yields is a vicious fallacy. On my own farm, where no chemical fertilizers are used, we average about forty per cent more crops per acre than the average for our section. There is much other evidence along the same line coming from other organiculturists. It would seem, that by propaganda, the farmer has been held in the subjection of the belief that chemical fertilizers will give him more bread and butter. The system which feeds that propaganda to him should be thoroughly investigated. In such a study it will be found that the chemical fertilizer manufacturers subsidize research in the agricultural experiment stations in such vast

sums that the researches that issue from that money cannot possibly be unbiased. The Government, by shirking its responsibility, by not furnishing sufficient money to keep all the agricultural scientists employed, permits some of them to practically become the employees of prejudiced interests. And the public is ground between these two mill-stones, for it gets the food that is produced under these unsatisfactory conditions.

POISON SPRAYS.

There is much evidence that when plants are healthy they will resist disease just as human beings will who are healthy. There is a considerable amount of scientific evidence in our agricultural journals that proves this.

It is an accepted fact in conservative agricultural circles that an oversupply of nitrogen causes a water-logging of plant tissues which cause certain fungus diseases to develop. It is so easy to create a condition of oversupply of nitrogen when chemical fertilizers are used. In the organic method, however, there is a gradual release of nitrogen from the organic matter at a pace that the plant can handle without trouble. I have shown previously how an oversupply of potash can reduce the available boron, and thus cause disease. Certain poison sprays are used to kill off the fungi that might be present in such diseased conditions. In my own practice of the organic method, and in the experience of many others, it has been found that we can keep disease down quite well. It is when the insect comes into the picture that it is not so easy.

However, in previous times orcharding was done without spraying and wonderful fruit was obtained. The Bible speaks of the land running with milk and honey. Old-time farmers have told me that they remember the time when no sprays were used and their fruit was tolerably good. Today the condition is becoming more and more acute with each year of spray poisoning. It seems to be bringing more and more insects. Is it possible that the increasing artificiality of the conditions of the trees is causing nature to produce more insects who wish to destroy these things which she considers an abomination? There is a great deal of evidence that the insect is a censor of nature appointed by it to destroy unwanted vegetation. The insect will come when there is a deficiency of some kind in the soil, or if a plant is growing out of its right medium, or where conditions of temperature are not optimum. There is a rhyme and a reason to the presence of insects and to the amount of them which are present. They are not merely an accident of mere occurrence. Nature has evidently trained them through the processes of evolution as a regulator of plant life. I can explain this by a medical experiment which I know of where fleas ceased to plague dogs who were fed vitamin C. The healthy skin they obtained by such feeding was distasteful to the fleas. And this is the point which I want to make in reference to insects. They have a taste different from a human being. Evidently they seem to relish sick plant tissue, or plants that have a sub-clinical amount of disease—that cannot be seen with the eye perhaps caused by feeding on chemical fertilizers.

I can give an illustration of what I mean by the insect as a censor of nature. I planted beans in two different pots—one a place where top-soil has been washing down on and enriching for years. The other at the place from which the top-soil has been washing. The Mexican Bean Beetle came only to the beans that grew on the poorer soil. Another illustration. I grew lettuces in a hot-house and aphides came and attacked them. Two months later I grew lettuces of the same variety on the same spot without fumigating and no aphids came. Why? Because the first plants grew in December when the days were short and there was no sunshine. The plants were stunted and the aphids seemed to like the taste of them. In February the days were longer and there was much more sunshine. The plants were healthier, and the aphids did not want them. I could cite a dozen other similar experiences.

Dr. Leonard Haseman, a distinguished entomologist of the University of Missouri, has done a great deal of work in this field and has shown many times in his experiments that insects come when there are deficiencies, especially of nitrogen. Dr. C. Stafford Brandt of the Federal Nutritional Laboratories at Cornell University performed an experiment in growing potatoes in which I furnished the compost. One section was grown with chemicals, the other with compost. At the end of the season Dr. Brandt introduced an equal number of aphids in each plot but he soon found that the majority of them landed up in the chemical plot. Evidently they liked something about the taste of the plant tissue grown with chemical fertilizers.

Incidentally our Soil and Health Foundation is negotiating with Dr. Haseman of the University of Missouri to give them a grant to study further into this question. A few months ago this foundation gave a grant to the University of Missouri for research to study potash rock fertilizers as against its equivalent in the form of chemical fertilizers.

Spraying poisons is an extremely unscientific procedure. It not only leaves dangerous residues on the crops which no amount of washing can completely get off, but it kills bacteria in the soil on which it falls. It is a sledge-hammer method. One entomologist once wrote me that it is a stop-gap device until something better is discovered, but it is about time that something better be substituted for the stop-gap which is becoming too expensive for the grower. It is leading him gradually into an economic impasse because of the gradually increasing number of sprays that the mounting insect menace seems to demand.

There are safer methods that should be experimented with. For example, the Nisbet Bug Catcher made in Texas which blows the insect into a bag attached to a blower on the tractor. There are methods of breeding enemy-type bugs which are let loose in the orchard and which attack the damaging insects. Much work is being done in California in this field. There are traps in which the female insect is placed which lures the male into it. There is a growing field of theory of planting certain plants nearby which either attract the insect or exerts a biologic effect over it which repulses the insect. The field has hardly been scratched. The entomologists have started with poison spraying and have found it so convenient that they close their eyes to any other methods. And they are becoming more daring. They are now working along new lines. Instead of spraying the tree or plant they expect to spray the poison on to the soil to be absorbed by the plant so that when the insect takes a bite of a leaf it will curl up its toes. But what about the people that will eat such a plant? Even to think about such a method is a downright crime against the people.

In conclusion, I wish to quote from two books showing that many experts believe in the possibilities of the organic method. First from the book called *The Business of Farming* published by the Oklahoma University Press, and written by Ladd Haysted, Agriculture Editor of *Fortune Magazine*. In it he says: 'The organic theory has not been adapted to commercial agriculture on a wide scale, although very recently a book entitled *Pay Dirt*, by J. I. Rodale, has attracted much attention and may bring in its wake wide experimentation and possibly an eventual significant acceptance'. Ladd Haysted mingles with the best there is in agriculture. He is a deep student and a practical man of agriculture. What he says should carry some weight.

William J. Hale, research consultant for Dow Chemical Company, a company that furnishes much chemical materials to agriculture, a man who is a distinguished chemist, recently wrote a book called *Farmer Victorious*, published by Coward McCann, and said in it: 'Chemical fertilizers gradually contribute to a degeneration among our plants, with the result that in due time our plant geneticists are constrained to import sturdier and hardier varieties of plants from more or less primitive lands in order, by cross breeding, to reinvigorate the seeds of our own plants.' In this book he recommends my book *The Healthy Hunzas*, which is an

attack on chemical fertilizers. He condemns poison spraying although he is a research consultant for a company that makes chemicals for spray poisons.

In closing, I would like to quote a statement made by Professor Firman Bear, Head of the Soils Department at Rutgers at the recent annual meeting of fertilizer manufacturers and dealers held at Rutgers. He said: 'the fertilizer industry should interest itself in the activity now going on to get more elements back into the soil and stop looking at organic farming with a jaundiced eye'.

Organic farming is here to stay.

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MANURING FOR LAND IMPROVEMENT AND CROP PRODUCTION.

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(Communicated by Dr. J. N. Mukherjee, D.Sc., F.N.I.).

ABSTRACT.

The paper deals with the results of manuring experiments on wheat and paddy conducted in Madhya Pradesh for some years past. The main points brought out are that in the case of wheat, for immediate increase in production, application of fertilizers is necessary, but from the point of view of land improvement, the superiority of organic manures is unquestionable. Deleterious effect of sodium nitrate on soil fertility has also been brought out. A long range policy calls for judicious use of both organic and inorganic manures. Among the fertilizers Nicphos has been found to be superior to ammonium sulphate.

2. As regards paddy, superiority of organic manures both from a short range and long term policy has been brought out. It is only to supplement its supplies that recourse to fertilizers has to be taken to get immediate results.

In this country where soils have reached almost the low levels of productivity, it is in fitness of things to examine how manuring can help immediately in stepping up production of food and fibre and yet maintain or increase the productivity of soil.

2. In Madhya Pradesh, the major important food crops are paddy, jowar and wheat, while cotton is the main fibre crop. In this paper, only wheat and paddy are dealt with. The conditions under which the two crops are grown vary widely, paddy being a monsoon crop and facilities for irrigating it in certain parts being available, adequate soil moisture is comparatively more assured. In the case of wheat it is grown during dry season and for which no irrigation is possible in this State except to a very limited extent. Because of the more complex nature of the problem, a large number of experiments were carried out on this crop at different stations in the wheat tract and it would be appropriate to deal with them first. Various manures, both organic and inorganic, were tried as also different methods of application of some of them. The details of these experiments are furnished in the statements enclosed, along with the results of several treatments. The results have not been statistically examined, but indicate the order of magnitude of yield responses to be obtained. The economics of manuring depends on the relative prices of manures and fertilizers and that of the produce. As they vary from time to time, the profits can be worked out from the extra yields obtained on the basis of relative rates.

3. Taking first the immediate effect on crop outturn, superiority of fertilizers over organic manures, is clearly evident, from the results of experiments Nos. 1 to 7 carried out at Powarkhera (Hoshangabad), Adhartal (Jabalpur) and Chhindwara. The increase in yield as a result of application of ammonium phosphate was up to 50 per cent as against up to 9 per cent with organic manurial treatment. At Chhindwara, where the soil is lighter and less retentive of moisture than that at the other two stations, the effect is less perceptible although greater than obtained by application of organic manure.

4. Although over most of the area, the crop is grown dry, there is microscopic acreage which is irrigated with well water. Under such conditions, too, the fertilizer, ammonium phosphate, applied singly, has given a response up to 33 per cent (Experiment No. 12) as against a maximum of 7 per cent with organic

manures (Experiment No. 11). Possibly the dose applied is not optimum. Hence the response to fertilizer is not so high as under dry conditions.

5. As regards the combination of the two kinds of manures, organic and inorganic, results of experiment No. 2 at Powarkhera for the dry crop and of most of the experiments on irrigated crop, show that addition of fertilizer to organic manures has enhanced the yield greater than the application of the latter singly. This combination has not, however, given as good a response as obtained by fertilizers applied singly.

6. Thus for an *immediate* increase in production the efficacy of fertilizers appears to be beyond doubt.

7. The next important aspect is the lasting effect of the two kinds of manures on soil. For this, experiments Nos. 13, 14 and 15 carried out at Powarkhera provided sufficient data. The residual effect of the several manures was studied over a period of two, eighteen and seven years respectively. In experiment No. 13, the plots previously manured with ammonium sulphate, were as bad as no manure plots whereas those given farm-yard manure showed an increase in yield up to 22 per cent, for a period of two years. The experiment No. 14 furnishes a very conclusive data obtained over a very long period, viz., 18 years. The harmful effect of sodium nitrate and the beneficial result of farm-yard manure are clearly brought out. The latter finding is also confirmed by the results of experiment No. 15. Thus from the point of view of land improvement, the superiority of organic manures is unquestionable. Equally true is the deleterious effect of fertilizers on the soil fertility.

8. Now as regards the third aspect, viz., protection against accentuation of damage through manuring by drought or rust, the period during which the experiments were carried out covered both these contingencies. The findings referred to earlier therefore hold good for this aspect too. Observation during the rust epidemic season showed that the plots manured with ammonium phosphate showed lesser damage than other treatments. Even during the dry season, the desiccating effect of this and the other fertilizer was not seen. Even in the case of farm-yard manure, plots treated with small dressings of 10 to 12 cart-loads were unaffected. In case of groundnut cake, however, germination was patchy particularly in a dry season, in the plots treated with it just at about sowing time. This effect was got over by applying the manure 5 to 6 weeks earlier.

9. Among the fertilizers, Niciphos has been found to be superior to ammonium sulphate. With an effective dose of 15 lbs. N per acre, the increase in yield due to these fertilizers has been 46 and 21 per cent respectively at Powarkhera. At Adhartal, the two fertilizers did not exhibit such a contrast with heavier application, viz., at 20 lbs. N but the difference was quite apparent in the smaller dose of 10 lbs. N per acre. At Chhindwara, too, the variation in the response to the two fertilizers was not appreciable, although it was higher with 15 lbs. N treatments. Even under irrigation, Niciphos has given greater response than the other fertilizer. Sodium nitrate has gone into disrepute. The effect of superphosphate was not perceptible since the need of the crop is more for nitrogen.

10. With regard to bulky manures, farm-yard manure and properly made compost are the best. Green manuring has not attained success worth the name. Besides, there are great limitations to adopting its use. In the wheat tract there is hardly a long break during the monsoon, to plough in the green crop. Further, its growth remains stunted on account of over saturation of soil moisture. Thirdly, there is the possibility of rains ceasing abruptly towards the month of September, in which case, the manure remains undecomposed. As regards oil cake, groundnut cake has given good results with earlier applications. But it is also exposed to the same danger of abrupt stoppage of monsoon in September. The risk, however, is relatively less since comparatively less moisture is required to bring about its fermentation. When supplies of farm-yard manure or compost manure are limited

recourse has to be taken to cake manure. Although obviously inferior to the cattle manure or compost, in its residual effect on soil fertility, the results do show that the plots treated with cake continued to give higher yield than no manure or fertilizer treated plots. Another good source is cattle urine. If conserved properly, it is more efficacious than cattle manure. With regard to the time and the doses the results are too clear to need any comment.

11. It will thus be apparent that these experiments have dispelled the popular prejudice against the manuring of wheat crop and furnish conclusive evidence with regard to the utility of several manures. They further indicate that although immediate and substantial increase in crop outturn could be obtained by resorting to the use of fertilizers, the value of organic manures in gradually building up soil fertility cannot and should not be ignored. A long range policy calls for judicious use of both organic and inorganic manures. Taking a period of 4 to 5 years, application of manures and fertilizers is positively a paying proposition and one that cannot be avoided any further except at dwindling prospects of wheat cultivation in the State.

12. Turning to the crop of paddy, only a few experiments conducted very recently will be enough to show the response of various manures. The details of layout, etc., have been furnished in the following tables. The experiment conducted at Kheri (Jabalpur) Station was confined to three different oil-cakes whereas at Labhandi (Raipur) besides oil-cakes, town compost, farm-yard manure, ammonium sulphate were tried and their residual response also studied. The effect of incorporation of Karanj leaf in various quantities too was observed.

13. The results although very much less exhaustive than those of experiments on wheat, are clearly indicative. The direct and residual response has been greatest with 40 lbs. N_2 applied in the form of town compost, farm-yard manure coming next in order. With regard to ammonium sulphate, the immediate increase in yield has been of the same order as with town compost, or farm-yard manure. But its residual effect has been negative. With regard to groundnut cake, both the direct and residual response has been of the same order. Groundnut cake appears to leave residual effect.

14. The second experiment on incorporation of karanj leaf has furnished equally interesting results although requiring to be confirmed. A dose of 3 tons produced the greatest response. The value of this finding is very great in that it shows a valuable source of manure to supplement compost or cowdung.

15. The experiment on oil-cakes at Kheri station has yielded conclusive results. All the three cakes have given almost the same response; 40 lbs. N_2 appears to be the optimum. As regards the economics, prices of til and linseed cake are higher than that of groundnut cake which is available at control rates. Under the existing circumstances, therefore, manuring with groundnut cake alone seems to be profitable.

16. Thus in the case of paddy under conditions of adequate soil moisture, superiority of organic manures both from a short range and long term policy is clearly brought out. It is only to supplement its supplies, that recourse to fertilizers has to be taken to get immediate results in the case of paddy.

Experiment number.	Name of experimental station.	Duration of experiment.	Crop strains used.	Treatment per acre.	Grain yield percentage (Wheat).	Increased outturn of grain in lbs. obtained as result of manurial treatment.
1	Powarkhera (Hoshangabad)	Five years, i.e. 1941-1945.	AO 13 & A 115.	(1) No manure—Control (2) 10 lbs. N ₂ as A.S. (Ammonium Sulphate) (3) 10 lbs. N ₂ as N.P.H.II (Nicaphos II) (4) 15 lbs. N ₂ as A.S. (5) 15 lbs. N ₂ as N.P.H.II	100.0 117.3 132.7 121.5 146.9	61 123 85 176
2	Powarkhera (Hoshangabad)	Five years, i.e. 1941-1945.	A 115	(1) No manure—Control (2) 15 lbs. N ₂ as F.Y.M. (Farm-Yard Manure) (3) 15 lbs. N ₂ as compost (4) 7½ lbs. N ₂ as F.Y.M. 7½ lbs. N ₂ as A.S. (5) 7½ lbs. N ₂ as compost 7½ lbs. N ₂ as A.S.	100.0 104.4 109.2 112.2 108.9	20 42 56 41
3	Adhartal (Jabalpur)	Four years, i.e. 1946-1949.	NP 52	(1) No manure—Control (2) 10 lbs. N ₂ as Amm. Phos. drilled with seed (3) 20 lbs. N ₂ as Amm. Phos. drilled with seed (4) 10 lbs. N ₂ as A.S. Phos. drilled with seed (5) 20 lbs. N ₂ as A.S. Phos. drilled with seed (6) 10 lbs. N ₂ as Amm. Phos. broadcast (7) 20 lbs. N ₂ as Amm. Phos. broadcast (8) 10 lbs. N ₂ as A.S. broadcast (9) 20 lbs. N ₂ as A.S. broadcast	100.0 140.1 150.8 128.2 143.6 124.7 123.7 112.2 115.9	155 186 109 168 85 91 47 61
4	Adhartal (Jabalpur).	One year 1948-49. Due to heavy rains in November and subsequent dry weather the crop yields were above normal during this season.	AO 90	(1) No manure—Control (2) 20 lbs. N ₂ as town compost before monsoon (3) 40 lbs. N ₂ as town compost before monsoon (4) 20 lbs. N ₂ as F.Y.M. before monsoon (5) 40 lbs. N ₂ as F.Y.M. before monsoon (6) 10 lbs. N ₂ as groundnut cake at sowing (7) 20 lbs. N ₂ as groundnut cake at sowing (8) 10 lbs. N ₂ as A.S. at sowing (9) 20 lbs. N ₂ as A.S. at sowing	100.0 168.7 102.0 106.7 111.7 128.3 139.4 135.0 170.6	43 10 33 58 139 194 172 346

Experiment number.	Name of experimental station.	Duration of experiment.	Crop strains used.	Treatment per acre.	Grain yield percentage (Wheat).	Increased outturn of grain in lbs. obtained as result of manurial treatment.
5	Chhindwara ..	Four years, i.e. 1932-1935.	AO 49	(1) No manure—Control .. (2) Synthetic manure at 4 tons .. (3) F.Y.M. at 4 tons ..	100.0 105.1 104.4	.. 25 23
6	Chhindwara ..	Five years, i.e. 1936-1940.	AO 49	(1) No manure—Control .. (2) 20 lbs. N ₂ as F.Y.M. .. (3) 20 lbs. N ₂ as synthetic manure .. (4) 20 lbs. N ₂ as A.S. with seed .. (5) 20 lbs. N ₂ as N.Ph.II with seed ..	100.0 97.8 104.2 113.1 116.9	.. -16 32 100 128
7	Chhindwara ..	Two years, i.e. 1941-1942.	..	(1) No manure—Control .. (2) 10 lbs. N ₂ as A.S. drilled with seed .. (3) 15 lbs. N ₂ as A.S. drilled with seed .. (4) 10 lbs. N ₂ as Ph.II drilled with seed .. (5) 15 lbs. N ₂ as N.Ph.II drilled with seed ..	100.0 111.1 123.7 111.1 130.9	.. 43 83 43 123
8	Powarkhera ..	Three years, i.e. 1940-1942.	AO 13, AO 90, A 115/ NP 52, NP 101 & E.B. 28 (irrigated).	(1) 5 tons F.Y.M. as basal dressing .. (2) 5 tons F.Y.M. plus 10 lbs. N ₂ as A.S. .. (3) 5 tons F.Y.M. plus 10 lbs. N ₂ as N.Ph.II ..	100.0 112.1 121.9	.. 128 233
9	Powarkhera ..	Four years, i.e. 1942-1945.	AO 13, A 115 & NP 101 (irrigated)	(1) 3 tons of F.Y.M. as basal dressing (Control) (2) 3 tons of F.Y.M. plus 10 lbs. N ₂ as A.S. (3) 3 tons of F.Y.M. plus 10 lbs. N ₂ as N.Ph. (4) 3 tons of F.Y.M. plus 20 lbs. N ₂ as A.S. (5) 3 tons of F.Y.M. plus 20 lbs. N ₂ as N.Ph.	100.0 116.3 125.1 116.1 132.2	.. 104 162 103 207

Experiment number.	Name of experimental station.	Duration of experiment.	Crop strains used.	Treatment per acre.	Grain yield percentage (Wheat).	Increased outturn of grain in lbs. obtained as a result of manurial treatment.
10	Chhindwara ..	Four years, i.e. 1932-1935.	AO 49 (Irrigated).	<p>(1) 4,000 lbs. of F.Y.M.—Control ..</p> <p>(2) 8,000 lbs. of F.Y.M. ..</p> <p>(3) 4,000 lbs. of F.Y.M. plus 100 lbs. A.S. ..</p> <p>(4) 4,000 lbs. of F.Y.M. plus 110 lbs. N.Ph.II ..</p> <p>(5) 4,000 lbs. of F.Y.M. plus 120 lbs. A.S. plus 120 lbs. Super Phos. single.</p> <p>(6) 4,000 lbs. of F.Y.M. plus 120 lbs. super phosphate single.</p>	<p>100.0</p> <p>102.1</p> <p>120.6</p> <p>121.6</p> <p>121.8</p> <p>97.7</p>	<p>19</p> <p>181</p> <p>190</p> <p>192</p> <p>— 20</p>
11	Chhindwara ..	Five years, i.e. 1936-1940.	A 112 (Irrigated).	<p>(1) No manure—Control ..</p> <p>(2) 20 lbs. N₂ as F.Y.M. ..</p> <p>(3) 10 lbs. N₂ as F.Y.M.—10 lbs. N₂ as A.S. top dressed</p> <p>(4) 10 lbs. N₂ as F.Y.M.—10 lbs. N₂ as N.Ph. top dressed</p> <p>(5) 20 lbs. N₂ as Karanj cake drilled with seed ..</p> <p>(6) 20 lbs. N₂ as A.S. top dressed ..</p> <p>(7) 20 lbs. N₂ as N.Ph.II top dressed ..</p>	<p>100.0</p> <p>107.1</p> <p>121.8</p> <p>120.0</p> <p>122.3</p> <p>125.9</p> <p>123.5</p>	<p>48</p> <p>148</p> <p>136</p> <p>152</p> <p>176</p> <p>160</p>
12	Tharsa (Nagpur).	Nine years, i.e. 1941-1949.	AO 49 (Irrigated).	<p>(1) No manure—Control ..</p> <p>(2) 25 lbs. N₂ as F.Y.M. ..</p> <p>(3) 10 lbs. N₂ as castor cake with seed plus 15 lbs. N₂ as castor cake top dressed.</p> <p>(4) 10 lbs. N₂ as A.S. with seed plus 15 lbs. N₂ as A.S. top dressed.</p> <p>(5) 10 lbs. N₂ as N.Ph.II with seed plus 15 lbs. N₂ as N.Ph.II as top dressed.</p> <p>(6) 10 lbs. N₂ as F.Y.M. plus 7½ lbs. N₂ as A.S. with seed and 7½ lbs. N₂ as A.S. top dressed.</p> <p>(7) 10 lbs. N₂ as F.Y.M.—7½ lbs. N₂ as N.Ph.II with seed plus 7½ lbs. N₂ as P.Ph. top dressed.</p> <p>(8) 10 lbs. N₂ as F.Y.M.—7½ lbs. N₂ as castor cake with seed and 7½ lbs. N₂ as castor cake top dressed.</p>	<p>100.0</p> <p>104.2</p> <p>114.9</p> <p>105.6</p> <p>133.0</p> <p>115.3</p> <p>126.3</p> <p>106.5</p>	<p>21</p> <p>71</p> <p>27</p> <p>157</p> <p>73</p> <p>126</p> <p>32</p>

Experiment number.	Name of experimental station.	Duration of experiment.	Crop strains used.	Treatment per acre.	Result of grain yield in per cent of control (Wheat).		Increased outturn of grain in lbs. obtained as a result of manurial treatment.	
					Direct.	Residual.	Direct.	Residual.
13	Powarkhera (Hoshangabad)	Manures applied during the year 1947-48 only and residual effect studied during two years, i.e. 1949 and 1950.	A 115	(1) No manure—Control ..	100-0	100-0	..	..
				(2) 10 cart-loads town compost	108-4	103-5	43	15
				(3) 20 cart-loads town compost	109-6	111-8	49	48
				(4) 10 cart-loads of F.Y.M. ..	103-1	110-3	16	42
				(5) 20 cart-loads of F.Y.M. ..	107-5	122-1	36	90
				(6) 4 mds. groundnut cake ..	72-0	111-0	-143	42
				(7) 120 lbs. A.S. ..	130-1	100-0	159	0-5
14	Powarkhera (Hoshangabad)	Manures applied during the period 1920 to 1931 and residual effect studied during the period of 18 years, i.e. 1932 to 1949.	A 115	(1) No manure—Control ..	100-0	100-0	..	..
				(2) 100 mds. F.Y.M. every year applied before monsoon.	125-3	142-3	154	128
				(3) 100 mds. urine earth every year applied as presowing cultivation.	121-6	119-8	131	60
				(4) 6 mds. castor cake applied every year at presowing cultivation.	125-4	109-1	153	30
				(5) 6 mds. treated castor cake applied every year with seed.	120-1	106-9	122	21
15	Powarkhera (Hoshangabad)	Manures applied during the period 1921-31 and residual effect studied for 7 years, i.e. 1932 to 1938.	..	(6) 1½ mds. sodium nitrate applied every year.	109-5	94-6	58	-16
				(1) No manure—Control ..	100-0	100-0	..	..
				(2) 100 mds. F.Y.M. every year	133-9	166-4	199	253
				(3) 300 mds. F.Y.M. every three years.	133-9	148-4	199	186
				(4) 100 mds. F.Y.M.—20 mds. lime every year.	124-3	133-1	143	126
				(5) 300 mds. F.Y.M.—40 mds. lime every three years.	126-6	140-9	156	160

Experiment number.	Name of experimental station.	Duration of experiment.	Crop strains used.	Treatment per acre.	Result of grain yield in per cent of control (Paddy).		Increased outturn of grain in lbs. obtained as a result of manurial treatment.	
					Direct.	Residual.	Direct.	Residual.
1	Labhandi (Raipur).	1948-49 The manurial treatment was given last year, i.e. 1948-49 and the residual effect studied this year.	..	(1) No manure	100.0	100.0	65	59
				(2) Town compost at 20 lbs. N ₂ per acre.	109.2	114.3		
				(3) Town compost at 40 lbs. N ₂	151.8	157.0	367	235
				(4) 20 lbs. N ₂ as cattle dung	121.5	130.6	152	126
				(5) 40 lbs. N ₂ as cattle dung	151.6	161.1	366	252
				(6) 10 lbs. N ₂ as groundnut cake.	115.3	133.3	108	125
				(7) 20 lbs. N ₂ as groundnut cake.	135.6	137.6	252	155
				(8) 10 lbs. N ₂ as Ammonium Sulphate.	120.2	102.7	143	11
				(9) 20 lbs. N ₂ as Ammonium Sulphate.	150.4	89.9	357	-42
				(1) No manure	100.0	..	..	..
				(2) One ton leaves of Karanj tree.	114.0	..	160	..
				(3) Two tons leaves of Karanj tree.	147.0	..	520	..
2	Labhandi (Raipur)	1949-50	..	(4) Three tons leaves of Karanj tree.	165.0	..	720	..
				(1) No manure	100.0	..	..	..
				(2) 20 lbs. N ₂ as Groundnut cake.	188.4	..	260	..
				(3) 40 lbs. N ₂ as Groundnut cake.	270.4	..	511	..
				(4) 60 lbs. N ₂ as Groundnut cake.	325.1	..	661	..
				(5) No manure	180.6	..	237	..
				(6) 20 lbs. N ₂ as linseed cake	262.5	..	477	..
				(7) 40 lbs. N ₂ as linseed cake	326.1	..	664	..
				(8) 60 lbs. N ₂ as linseed cake				
				(9) No manure	181.0	..	251	..
				(10) 20 lbs. N ₂ as til oil-cake ..	266.0	..	490	..
				(11) 40 lbs. N ₂ as til oil-cake ..	310.8	..	620	..
3	Kheri (Jabalpur).	Four years—1942 to 1945-46.	..	(12) 60 lbs. N ₂ as til oil-cake ..				
				(1) No manure	100.0	..	..	..
				(2) 20 lbs. N ₂ as Groundnut cake.	188.4	..	260	..
				(3) 40 lbs. N ₂ as Groundnut cake.	270.4	..	511	..
				(4) 60 lbs. N ₂ as Groundnut cake.	325.1	..	661	..
				(5) No manure	180.6	..	237	..
				(6) 20 lbs. N ₂ as linseed cake	262.5	..	477	..
				(7) 40 lbs. N ₂ as linseed cake	326.1	..	664	..
				(8) 60 lbs. N ₂ as linseed cake				
				(9) No manure	181.0	..	251	..
				(10) 20 lbs. N ₂ as til oil-cake ..	266.0	..	490	..
				(11) 40 lbs. N ₂ as til oil-cake ..	310.8	..	620	..

WHICH WAY DELUDED HUMANITY ?

By CHARLOTTE M. HOAK, *California, U.S.A.*

(Communicated by Dr. N. R. Dhar, F.N.I.)

Humanity stands at the cross-roads today in the most critical situation civilization has ever faced. If only a small proportion of the wasted millions poured into the insatiable maw of using atomic forces to produce atom bombs for wholesale destruction could be halted in its mad race to pile up more and better bombs we could make some real progress. As agriculturists it is our most urgent duty to see that these misapplied energies are turned into the proper channels. There is a crying need for more investigation in the field of human nutrition in its vital relation to the soil as a living organism. Stricken humanity needs immediate help in extricating itself from its present perilous position. Soil and food are inextricably bound together, and the rapid depletion of soils the world over, either by impoverishment or wrong methods of fertilization bids us pause to consider sanely where we stand. No progress can be made without the maintenance of a high standard of health freed from the lurking dangers of 'the hidden hunger' and the all too evident increasing malnutrition diseases which have multiplied with such astounding rapidity during the last few decades. Both are matters of profound importance which concern us both in the Orient and the Occident, the one with its famine stricken millions and the other with its millions starving on full stomachs.

The findings of recent researches on the intimate relation of health to the health of the soil have revealed that most of our ill-health stems back to the flagrant abuses of the soil which could be so easily overcome if we could be made to realize the vital importance of the correct methods of soil renewal. Repeatedly, our most progressive chemical laboratories have been furnishing us with the most convincing data which reduced to its lowest terms understandable to scholar and layman is: poor soil, poor food, poor health. It is this vicious circle we should break. It is with profound interest that I have read and digested as far as possible, with my limited experience, the helpful chemical research in agricultural fields done by your leader, Dr. N. R. Dhar, Head of the Chemistry Department of the University of Allahabad. The various reprints of the *Proceedings* of the National Institute of Sciences of India and his invaluable book on Biochemistry should be in the hands of every progressive agriculturist.

Of special interest to us in the semi-arid south-west is the Reclamation of 'Usar' (alkaline) Land by Treatment of Molasses and Press-mud. Of great interest throughout the country is the new light thrown on the direct nitrification of the soil.

Since the time of Baron von Liebig the Western World, Europe, and especially the United States, has been under the domination of the N P K group which is deeply entrenched in the mistaken belief of the efficacy of the Big Four chemicals, nitrogen, phosphorus, potassium and calcium. Already we are seeing the handwriting on the wall; and, if we continue in the error of our way, we are eventually going to reach the point in the near future when the abused soil will not produce enough to feed us. During World War II, having the supervision of many Victory Gardens, I had a chance to observe the devastating effects of over-doses of commercials applied by many zealous gardeners.

Having taught, lectured on, and practised organic methods all my life, I have read critically to find out what is being done in all parts of the world. Situated as I am in the semi-arid south-west, near Los Angeles, 34° 10' N. and 118° 30' W. I find Dr. Dhar's researches helpful. Here we have one of the five typical Mediterranean climates where there are short mild winters with a rainfall from 7 to 20 inches, and long, dry, rainless summers. Throughout the years, I have learned to adapt my agricultural practices to this particular climatic region. I do not adhere to any particular group, but take the best from all. In the first place, I use no commercial fertilizers, for, in the long run, they deplete the soil. For renewal, I compost, cover-crop and sheet-compost.

I have used several methods of composting, the Indore, the Bio-dynamic, Maye E. Bruce's Quick Method Composting and the four week method, advocated by R. Sanford Martin with his activator, Humisite. This product is very rich in humic acid and has a high bacterial count. This latter method, designed by its originator to meet our conditions here in the semi-arid south-west is the best and easiest method I have found, especially for the smaller home gardens. There is no heavy and laborious turning, no soil to add to furnish extra bacteria. No ashes or lime are added, for the pH here is already far too high. The material for composting is first dried and mixed. It is made up of the miscellaneous vegetable wastes which accumulate in the garden. A ventilated compost bin made of redwood is far better than a pile, for it keeps the heat in and furnishes sufficient aeration. Starting with a pile 12 inches high, which is packed in evenly and watered down thoroughly, you proceed to put on your light sprinkling of Humisite, continuing these two layers until you reach the top. The last layer at the height of six feet is sprinkled with Humisite, and the whole surface of the bin is covered with several thicknesses of newspaper. By the next morning the heat generated will be sufficient to kill any weed seeds and destroy any lurking plant diseases. You test the moisture by a curtain pole sharpened at one end, inserted diagonally. When pulled out, if dry and hot, more water should be added. After the heat has subsided you can add earthworms, but it is not absolutely necessary. You can apply the finished product without sieving, for it is quite fine and black, making an excellent mulch or the best sort of organic material to enrich your soil. In this semi-arid region where the blazing heat burns up the humus in the soil, it is necessary to have a quick and easy way to supply new humus. The Indore method of composting, which requires double turning, the Bio-dynamic, which is involved with rituals and special activators which are given out to the membership of the society or subscribers only, and Maye E. Bruce's Quick Method, which is adapted from the Bio-dynamic, all have their drawbacks here where we do things on a big scale.

Cover crops are planted, or should be, so as to keep all unused ground summer and winter from being wind and water eroded. *Melilotus indica*, yellow clover, is one of the cheapest and best winter cover crops. Sown in October and plowed in during the early spring, it furnishes some humus and considerable nitrogen from the air by the bacteria on the root nodules. Oats and purple vetch make another good winter crop; but the legume which has the largest amount of succulent herbage is the Windsor bean. The nodules are particularly large and numerous. In addition, you have the benefit of an edible crop. We have two very fine self-sown cover-crops, the bur-clover, *Medicago hispida*, naturalized from Europe, and a native dwarf lupine, *Lupinus micranthus*. They both come up naturally with the advent of the fall rains, and we have found that the land which has been naturally cover-cropped by them is much richer in nitrogen content.

Composting and cover-cropping consume so much time that renewal of the soil through the addition of organic material is not practical where we do agriculture on such a large scale as we do in California. Direct nitrification of the soil by a process similar to photosynthesis is the answer, and furnishes the techniques which are very simple as Dr. Dhar proves conclusively in his experiments at Allahabad.

I have always believed in the efficacy of sheet-composting and have tried it out in a number of projects. Several years ago, while I had charge of the Agriculture Department of the Gateway Estate at Ramona, San Diego County, I used this method very successfully. This estate of 168-A was situated in the foot-hills, an old-grazed cattle range badly eroded. Some gullies were three and four feet deep. Before I took charge the land had been plowed up and down, waste material had been burned, no cover-cropping had been done and the water supply was furnished by an antique system using hundreds of feet of hose with tall sprinklers running usually in the sun and wind. With my force of workmen I proceeded to remedy the results of these ruinous practices. First, with a disc-terracar, I had the land contoured. The irrigation system was next renovated, changing from $\frac{1}{2}$ inch pipes to 2 inch ones, with low tripod sprinklers delivering the water at night, 2A inches being put on at one time. We invested in a Ford-Ferguson tractor, a large power-run insilage cutter, and a spring-tooth plow. Thus, we were working with all power machinery. Cover-crops were planted at the proper time, *Melilotus indica*, yellow clover, and oats and *Vicia purpuria*, Purple Vetch were used exclusively on the different acreages. Windsor beans, on account of their rank foliage and large bacteria bearing nodules, were used in the vegetable plots to furnish food and extra material for composting. Composting by the Indore method (which the Directors of the estate requested) took time and much labour. I resolved on a short cut-sheet-composting programme and made a survey of available waste materials which I could get for nothing. I set my workers to collecting it. Turkey raising and dairying were the chief industries of the locality. The cow-manure was left to pile up and go to waste. With two large trucks we hauled load after load before it was leached by winter rains. The turkey raisers were glad to have their pens cleaned up and offered us some of their most valuable material which they called 'turkey poult'. This is made up of turkey manure, mixed with a ground milo maize and bran mash on which the young turkeys are fed. (Rich in carbohydrates enough to satisfy Dr. Dhar's requirements.) After we had stacked loads of these manures at regular intervals along our main garden plots, we next collected in all the waste vegetable material the neighbourhood offered. There had been an early fall rain, and one rancher offered us as many bales of spoiled hay as we wanted.

After the land had been contoured we spread the 'turkey poult' and dry vegetable waste and set the sprinklers for an all night run delivering 2A inches of water, the average fall rain amount. The usual fall rain came before we needed another irrigation. In the early springs-planting season, we plowed and worked in the sheet-composted material at the same time. We had test plots of *Melilotus indica* and the untreated plots planted for comparison. On these areas we planted summer squash, bush beans, carrots, beets, lettuce, chard, etc. From the sheet-composted area we harvested the most bountiful crop, the vegetables having the appearance of having had a strong commercial nitrogenous fertilizer applied. With sheet-composting every bit of the plant food goes directly into the soil and the action of the hot sun on the surface of the area composted precipitated nitrogen directly from the air. Of course, you must necessarily allow the interval of several months to elapse before you get the complete nitrification.

In all my work with soils I watch the pH very carefully, for this is a matter of great importance in the semi-arid south-west where the soil is nearly always too alkaline to produce the best results. We find from wide experience that the best results are obtained from soil which is neutral, or slightly above or below neutral, $6\frac{1}{2}$ to $7\frac{1}{2}$ pH. To acidify the soil, we find the volcanic soil sulphur which is mined some twenty-five miles south of the border at Calexico, Mexico, to be excellent. The appended analysis made by the Geo. W. Gooch Laboratories, Ltd., Analytical and Consulting Chemists of Los Angeles, is a revealing one.

*Laboratory Report.***Sample sulphur**

Mark 70% soil sulphur

Based on sample as submitted

Moisture (100°C. to constant)	..	..	..	1.60%
Sulphur (by extraction)	..	..	..	73.46%
Ash	..	..	..	24.60%
Acidity (as sulphuric acid (H ₂ SO ₄))	..	..	..	0.01%
Arsenic (As)	..	..	..	Nil

The volcanic soil sulphur compounds create acidity so essential in our basic soils, make other plant foods more available, furnish an essential plant food element, condition the soils along with manures and phosphates, and lastly develop more vigorous and healthy plants.

Analysis of Ash.

Silica (SiO ₂)	..	..	..	65.80%
Iron oxide (Fe ₂ O ₃)	..	..	..	2.20%
Aluminium oxide (Al ₂ O ₃)	..	..	..	8.90%
Titanium oxide (TiO ₂)	..	..	..	0.45%
Calcium oxide (CaO)	..	..	..	6.60%
Magnesium oxide (MgO)	..	..	..	2.85%
Manganese oxide (MnO)	..	..	..	Trace
Total sodium oxide (Na ₂ O)	..	..	..	2.60%
Total potassium oxide (K ₂ O)	..	..	..	1.55%
Sulphur trioxide (SO ₃)	..	..	..	6.35%
Phosphoric anhydride (P ₂ O ₅)	..	..	..	0.10%

Spectrographic Qualitative Analysis : Estimated Quantity.

Silicon	..	..	..	..	10.0%
Calcium	..	..	..	..	10.0%
Aluminium	..	..	..	1.0% to	10.0%
Magnesium	..	..	..	1.0% to	10.0%
Iron	..	..	..	1.0% to	10.0%
Sodium	..	..	..	0.1% to	1.0%
Potassium	..	..	..	0.1% to	1.0%
Manganese	..	..	..	..	0.1%
Strontium	..	..	..	..	0.1%
Titanium	..	..	..	0.01% to	0.1%
Barium	..	..	..	0.01% to	0.1%
Chromium	..	..	..	..	0.01%
Copper	..	..	..	..	0.01%
Boron	..	..	..	..	0.001%
Silver	..	..	..	..	0.0001%
Arsenic	..	..	..	..	None

As a garden consultant, I advise my patrons to have a spectroscopic analysis made of their soils so that they are not working in the dark. They know the pH, the principal mineral constituents, the trace minerals and the percentages of coarse sand, fine sand, silt and clay. From these basic findings, we can build up almost any soil so that it produces superior vegetables and fruits. Organically raised food grown by gardeners who follow such a regime is not only good to look at but is body-building and comparatively disease resistant.

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HUMUS OR ARTIFICIALS.

By J. G. SHRIKHANDE, *Government Agricultural College, Kanpur.*

(Communicated by Prof. N. R. Dhar, F.N.I.)

In approaching the subject of manuring the question may be asked, why do we manure at all?

The most obvious answer is that manures are applied in order that farm and garden crops may be grown. Yet this answer is hardly sufficient, for it has been proved at the Rothamsted Experimental Station that crops can be grown of a sort, where for many years no manure has been added; and there are many meadow lands which still yield a fair crop of hay and have not received any manurial dressing for several years. In such cases the plants are supplied with nourishment from the materials rendered available in the soil through the action of weathering agents, etc.

The soil cannot be dissociated from the atmosphere and to consider the soil in a proper manner one has to take into consideration atmospheric water and temperature. The soil is an anchorage for the plants growing on it, the seat of root development, root nutrition, all plant changes, whether they be chemical, physical or biological. A soil is a very complex material in regard to its chemical composition and physical structure. The mineral matter exists in various grades from stones to colloidal clay being in fact a minutely discontinuous structure.

Clay consists of secondary minerals, such as kaolinite, beidellite, montmorillonite, etc., complex aluminosilicates formed by the decomposition of the original minerals in the parent rock, its particles fall within the colloidal range and have very great surface activity. As a result, a clay soil is far more active physically and chemically than a sandy one. Associated with this mineral colloid is humus an organic product of biochemical origin. Humus is particularly important in those soils which are deficient in clay as it then provides the colloidal matter that is otherwise lacking and so improves their physical and chemical properties. Organic matter is also beneficial to very heavy clays by opening them up and improving their structure.

The rôle of organic matter in the soil is undoubtedly important. Although Howard's writings may have concentrated attention on this problem, the discovery of the importance of humus and organic matter is not of recent origin. The high crop producing value of human and agricultural waste has been known for centuries and advantage has been taken of it by the Chinese, King (1926). As early as 1893 Voelcker considered 'the spread of a good system of utilizing human and household refuse, street sweeping, etc., on the land as a most potent factor in the improvement of Indian agriculture'. Leather too emphasized this point in 1895 in India and Russell in England in 1922. Even before Voelcker, Baker in 1885 in his book on 8 years tour of Ceylon describes the cheapest way of making manure on an estate giving details of the 'Geoffrey' pit in which refuse is packed for fermentation.

In the last few years after the vigorous propaganda in England and colonies by Howard on his retirement from India in favour of his 'Indore Process', increased attention has been given by agricultural workers to the question of the respective merits of natural humus and artificial fertilizers in restoring soil fertility. Even Lord Hankey was persuaded by this propaganda to support organic manuring and he wrote a comprehensive article in a leading London Weekly in 1944. There had just an appeal made also in the House of Lords for a Government enquiry involving long-term experiments to test the theory of humus *versus* artificials. The official

response was hardly sympathetic to the idea, the Government view being that the problem remains one of using humus and artificials in the right proportions.

Compared with artificials organic manures have been claimed to be of specific importance in some direction. With the discovery of vitamins and their importance in nutrition a further weight has been attached to the possible rôle of organic manures in soils. The animal obtains its vitamins from the plants which it consumed as food and the plant manufactures them or perhaps obtain them from the soil and it appears probable that the micro-organisms which are abundant in humus play an important part in the synthesis of vitamins. Evidence to this effect has been brought forward by several investigators. The effect of injection of yeast extracts and extracts from biological media has been studied by Hausen (1930), Virtanen and Hausen (1933 and 1934) and Subrahmanyam and Siddappa (1933). Hausen observed that the addition of vitamin C to plants grown in sterile water-culture before flowering increased their height and weight and up to a limit the vitamin C content. Virtanen and Hausen noted that the plants were able to take up the growth regulating factor (or factors) in the yeast extract through their roots and thus suggested the importance of micro-organisms in the soil. Subrahmanyam and Siddappa studied the effects of extracts from activated sludge, organic manure and soil in addition to yeast extract and came to the same conclusion as obtained by the previous workers. McCarrison (1926) showed that the grain produced on farm-yard manure contained more vitamins than that grown with artificials. Vishwanath and Suryanarayanan found that seed from a crop of ragi (*eleusine coracana*) grown with farm-yard manure gave greater yields than crops sown with seeds raised on artificials. Ramiah (1933) reported that the forage crops grown on farm-yard manure are similarly rich in vitamins. L. J. Harris analysed wheat grown on organics and inorganics at Rothamsted but found no difference in the vitamin content of the differently manured grain.

Although the importance of growth-regulating factor is amply demonstrated in the growth of plants and organisms there are certain other points which need further elucidation. With the existing data and conflicting views it is not possible to conclude with regard to the influence of manuring on the nutritional value and yield of foodstuff. Till now the stimulating effect of yeast, biological media and other growth regulating substances has been shown only on the growth and height of stems and flowering, but not on the yield, a point of fundamental importance to the farmer. Secondly, the temperature in the compost may be high enough to destroy any existing carotene and vitamins during the composting process. It has been shown at Jealott's Hill that carotene is correlated to the protein content in the herbage, and it is well known that carotene is easily transformed into vitamin A in the body. Incidentally this vitamin is the main growth-promoting factor in animals. Therefore judicious manuring with organics and inorganics will produce good and healthy herbage with an adequate protein and carotene content. It may thus appear premature to suppose at present that organics produce foodstuffs richer in vitamins than inorganics.

The advocates of organic manuring recall the age-long destructiveness of man to soil. Once famous granaries and hunting grounds in the Middle East, North Africa, China and Russia, have long since become deserts and great civilizations have perished in consequence. The same process is apparently proceeding apace in North America, Australia, Africa and elsewhere, so new lands of promise are threatened in Europe and even in Britain. The compostors attribute this widespread erosion to the failure to put back what has been taken out by over-production with the result that the essential humus is disappearing. Modern methods, including certain chemical fertilizers are indicated as a potent contributory cause. For a hundred years now since Liebig started applying chemistry to agriculture, farmers have relied increasingly on artificials. No one denies that bumper crops can be obtained by this method as proved in the last two Wars but the compostors

believe that chemicals poison the life in the soil, destroy the earthworms, which aerate it and probably also the mycorrhiza, the beneficial fungi which it has been found give a stimulus to health and resistance to disease—highly contentious arguments.

Sir Albert Howard to whom the present controversy over organics *versus* artificials is due, had become a faddist and in his zeal for his Indore method of composting went to the extent of condemning some standard and well established methods of maintaining the organic matter content of the soil. He emphasized with almost a religious fervour that humus manufactured only by the Indore method could alone bestow the blessings and advantage on soils and crops attributed to organic matter. He even called into question the well established practice of green manuring as a source of humus and insisted on composting of the green manures before incorporation into the soil.

The arguments adduced in favour of composting were essentially twofold:—

- (1) That composting is necessary to adjust the C-N ratio of crude vegetable materials without which operation the organisms responsible for decomposition are presented with an abundant supply of energy producing material but experience a deficiency of readily available N necessary for building up their body tissues. Consequently when green manure is added to the soil, the micro-organisms, augment the nitrogen supply from the only possible source, viz., the soil nitrate. If this happens, there is a grave risk of temporary nitrogen starvation for any crop grown contemporaneously.
- (2) Decomposed material contains accessory food materials whose nature and properties though still almost obscure affect growth vitally and favourably. In particular, as regards plantation crops such substances encourage mycorrhizal habit of root development which is presumed to be specially beneficial.

Of these two arguments the first is based on certain well established principles of biochemistry and micro-biology, but begs the question as to whether all vegetable material requires this pre-treatment and in particular, whether green manures as used on tea estates contain enough nitrogen to satisfy the normal microbiological economy when decomposing. Author's work (1945, 1946, 1947) at the Tea Research of Ceylon has borne chiefly on this question of nitrogen metabolism of decomposing green manures.

The Carbon-Nitrogen Ratio of Green Manures.

The rapidity with which loppings of green manures or tea pruning leaf are dispersed when allowed to remain on the surface of the soil gives a rough indication that their nitrogen content is not of the same order as the mature wastes from either annual or perennial plants. On examination, the chief green manures in Ceylon and other readily available wastes were found to be easily divisible into two distinct groups of which Table I provides details.

The first group comprises materials which are grown interplanted with tea; the second, with respect to the first and last entries represents waste material from outside sources. *Grevillea rebusta* is grown in tea but its contribution is from a leaf fall and not from a direct lopping for incorporation. It is at once evident that on the basis of any theory that the carbon-nitrogen ratio is relevant to the question of disposal of vegetable matter and that the ratio 10 is optimal, material grown with the tea needs no adjustment at all and can be used without scruple as a green manure. In fact since, as will be shown later, a portion of the nitrogen is readily mineralized, to compost this material under circumstances where leaching losses cannot at all times be avoided, is likely to lead to a definite loss of nitrogen available for plant nutrition and not to its conservation. In this respect the position of tea

TABLE I.
Carbon-Nitrogen Ratios of Waste Materials.

Material.				Carbon %	Nitrogen %	Ratio.
Type A.	Frythrina lithosperma	..	..	40.62	2.54	15.97
	Gliricidia sepium	..	..	40.48	2.74	14.77
	Tithonia diversifolia	..	..	36.91	3.37	10.96
	Tephrosia vogelii	..	..	43.40	3.46	12.56
	Tea pruning leaf	..	..	42.63	3.19	13.38
	Waste manufactured tea	..	..	42.73	3.97	10.75
	Green weeds	..	..	34.99	2.01	17.43
Type B.	Andropogon nardus	..	..	39.92	1.37	29.07
	Grevillea robusta	..	..	48.78	1.04	47.10
	Pennisetum sp.	..	..	36.92	0.96	38.50

as a subject for green manuring is specially favourable. It is a perennial kept artificially in a continuous vegetative phase and as far as is known is capable of absorbing and utilizing nitrogen over the greater part of its growth cycle between one pruning operation and the next.

The Nitrogen Factor of Green Manures.

The consideration of carbon-nitrogen ratios provides only a working rule for the division of vegetable material into categories requiring or not requiring fermentation as the case may be, in order to be sure that no ill-effects will follow their use. A more detailed and conclusive picture is given by the determination of the 'nitrogen factor' of the material. The nitrogen factor is defined by Hutchinson and Richards as 'the additional inorganic nitrogen immobilized as organic nitrogen by 100 gms. of any material in the process of decomposition'. If, in accordance with the theory described earlier, a material does not contain enough nitrogen for its own decomposition, the deficiency can be made up from inorganic sources. At the end of the fermentation the quantity of added inorganic nitrogen used by the organisms will have been elaborated into organic nitrogen in their tissues. Since it is simple to evaluate inorganic and organic nitrogen separately, a balance sheet of the two types at the beginning and end of a fermentation readily gives the amount of nitrogen converted, or, to use the originator's phrase immobilized.

From a large number of such balance sheets four typical examples are gathered together in Table II.

TABLE II.
Nitrogen Transformations in Fermenting Green Materials.

Material.	Original material			Fermented material			N. factor (d) - (a)	N. loss (c) - (f)
	Organic N. per cent (a)	Mineral N. % (added) (b)	Total N. per cent (c)	Organic N. per cent (d)	Mineral N. (found) (e)	Total N. per cent (f)		
Andropogon nardus	1.37	1.09	2.46	1.98	0.41	2.39	+0.61	0.07
Tephrosia vogelii { (A)	3.46	1.11	4.57	2.72	1.56	4.28	-0.74	0.29
(B)	3.46	Nil	3.46	2.85	0.67	3.52	-0.61	-0.06
Tea leaf	3.19	Nil	3.19	2.53	Nil	2.53	-0.66	0.66

The *Andropogon nardus* (Maana grass) shows the course of events followed when a material that has too wide a carbon-nitrogen ratio (see Table I) for immediate use is decomposed. It absorbs inorganic nitrogen and elaborates it and finishes with more 'organic' nitrogen than it had to start with; it consequently has a positive nitrogen factor. Such a material used directly would accordingly cause temporary nitrogen starvation.

Tephrosia as instanced by example (A) finishes its fermentation with less 'organic' nitrogen and more inorganic nitrogen than it possessed or was given to start with, and consequently its nitrogen factor is negative. It also loses an appreciable quantity of the total initial nitrogen. On the evidence of this example it should be possible to decompose Tephrosia satisfactorily by means of its own nitrogen only. Example (B) using the same material without any addition shows this to be the case. The nitrogen factor is negative and of the same order as in the previous example.

Tea leaf behaves in a manner similar to green manure of narrow carbon-nitrogen ratio in that it decomposes without additional nitrogen, but it has failed in our tests to produce any mineralization. Its negative nitrogen factor is thus equivalent to its nitrogen loss.

Before expecting a discovery to be universally accepted it has to be backed up by scientific data and field experiments collected over several years particularly in agricultural research but Howard hated long range field experiments and detested statistics. That being so, some of his claims were hardly justified since they were based on a few isolated instances. The function of earthworms is undoubtedly important in soil processes in so far as they break up and distribute plant residues through the top soil but they do not aid humification as has been commonly supposed. The claim that fertilizers reduce the earthworm population is not supported by work at Rothamsted. The plots manured with ammonium sulphate had almost the same earthworms population as the check plots. At Cornell manured plot had about four times the earthworms population as on unmanured. As long as acidity is corrected there is no danger of earthworm population to be adversely affected.

The claims that micro-organic population and mycorrhiza are affected by treatment with ammonium sulphate is also based on one or two instances. In fact Rothamsted experiments have shown that the judicious application of nitrogenous fertilizer results in increased microbiological activity. The only instance where mycorrhiza was affected was in one of the experiments of Rayner at forestry nurseries at Wareham. The soil was thin and acidic and lacked in colloidal material and hence had reduced buffering action. Such isolated instances need addition of lime to correct the acidity.

The fertility of the soil depends on a number of complex factors besides the intrinsic characteristic of the soil. The use of manures and fertilizers is only one of the several factors in maintaining soil fertility and crop production at a high level. Proper drainage, maintenance of soil organic matter, prevention of soil erosion, improvement of the physical condition of the soil, liming wherever needed, are all necessary for productive farming.

It is an established fact that all cultivated soils in India are invariably deficient in nitrogen, generally deficient in phosphorus and frequently deficient in potassium. It naturally follows therefore that nitrogen stands foremost in the list of essential elements to be added to the soil followed by phosphorus and potassium.

Farm-yard manure is one of the important organic manures used in India. The quantity of cattle manure produced in India is estimated at 120 million tons on dry basis equivalent to 200 million tons of wet manure (Acharya, 1949). The composition of this manure on dry basis is about 0.5% N; 0.25% P_2O_5 and K_2O . On the basis of crude estimate for availability of nutrients, one ton of average

F.Y.M. provides 5 lbs. of N and K_2O and 1 lb. of P_2O_5 . According to Parr (1946) the output of F.Y.M. is only sufficient to manure one acre in every ten.

The amount of town refuse compost produced annually in India approximates to 10 million tons and this amounts to 10 million tons supplying 0.05 million tons of N, 0.04 million tons of P_2O_5 and 0.1 million tons of K_2O (Acharya, 1949). The average composition of this compost is 0.8% N, 0.9% P_2O_5 and 0.8% K_2O . Even if the village compost scheme is successful it is estimated to produce only 1 ton compost per acre of cultivated land.

The quantity of N and P_2O_5 put together in F.Y.M. and composts is thus hardly enough for getting increased yield of crops at the rates these nutrients are worked out for different crops. It may be pointed out that any means of increasing crop production with consequent increase in crop residues as a result of judicious application of inorganics will increase the amount of organic matter which can be composted or incorporated as such with an appropriate dose of nitrogen for satisfactory decomposition.

Composts and organic manures are slow acting. It is also not known how much of the nitrogen in composts becomes available and over what period. Views are conflicting under field conditions, though Shrikhande (1943, 1945) has shown under laboratory conditions that 60% nitrogen becomes available from green manures and composts and oil cakes in 60 to 70 days beyond which there is insignificant mineralization. This slow action of organic manure is hardly going to be of much help in the present crisis.

When seeds germinate and shoot comes up the plant has to fend for itself and its tiny rootlets have to hunt for available food failing which it dies. For this readily available nitrogen is necessary. This need can easily and readily be met by sulphate of ammonia or nitrate. Moreover, in the first 4-5 weeks after germination, nutrient requirements particularly of nitrogen are heavy and they can be met readily only by quick acting manures like the artificials. After this the nitrogen requirements slow down—at this stage organic manures or composts may be serviceable.

Therefore under existing conditions artificials followed by organics will be more useful and consistent with reasoned crop growing and it should be clearly understood that both the forms of manures can be complimentary but never competitive in view of the advantages conferred by both on the plant and the soil. What is needed is a judicious application of organics and artificials the former for maintaining the soil in good tilth and conferring other advantages on the soil and plant and the latter for effecting quick growth and increased yield. What is needed today is an increase in quantity of agricultural produces to save people from starvation. The question of quality by organic manuring can be settled by laying down long term field experiments to settle the controversy.

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THE ORGANIC MATTER PROBLEM OF THE NETHERLANDS SOILS.

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(Communicated by Dr. J. N. Mukherjee, F.N.I.)

The ever increasing intensity of agricultural practice makes high demands on the supply and availability of plant nutrients in the soil, i.e., inorganic substances which in different compounds are naturally present in the soil or are added to it by manuring. Climatological conditions in the Netherlands are such that not only the intake of the various substances by the crop but also the considerable losses in the permeating water must be taken into consideration. Rainfall and the amount of drainage which were determined by J. G. Maschhaupt (1) in his lysimeter investigation are shown in Table I for the different seasons with soils under cultivation.

TABLE I

	Mean rainfall in mm.		Drainage in % rainfall.	
	Autumn	190	Autumn	21.3
Mean of 15 years 717	Winter	154	Winter	65.0
	Spring	142	Spring	31.4
	Summer	231	Summer	3.9

Soil investigation carried out throughout the country according to fixed standards enabled us to form a tentative opinion of improvements that could be made in the manuring condition of land for cultivation. The subject was reported upon on the occasion of the United Nations Conference on the conservation and utilization of resources, which was held on 17th August, 1949, at Lake Success (2). As regards the importance of organic manuring in the Netherlands and the raising of the production-level by improving the soil-structure, only some general statements could be given as the number of quantitative data then collected were insufficient. The object of this paper is to provide some information as to the progress of this research.

The connection between the intensification of agriculture and the organic matter supply of the soil is quite different from the relation to inorganic crop nutrition referred to above. The increase of production by better manuring methods generally means that the soil is enriched with organic matter through a greater root development. The cultivation of after-crops following a main crop means that the soil is covered for a longer time. Adverse climatological influences on the structure are thus prevented. In the Netherlands it is of paramount importance where the organic matter problem is concerned, whether or not sufficient attention is paid to the soil structure, as it is immediately connected with the air and water supply and the effectiveness of fertilizers added to the soil. Moreover, it is of importance to know in the case of organic manuring whether or not the way in which plant nutrients become available to the crop, may result in an increase of the quantity and quality of the crop.

The organic matter percentage of the Dutch land under cultivation varies considerably. Arable land contains from a few per cents to 30% or more. The organic matter of the turf of permanent grassland may vary from a few per cents to 60% or more. It stands to reason that water conditions in the past and at present

have had a great effect on this percentage (in the Netherlands especially the water table and drainage conditions). The temperature which affects the rate of decomposition of organic matter may, as far as this country is concerned, be characterized as follows: mean temperature in spring 9.4° , in summer 17.4° , in autumn 10.4° and in winter 2.9° C. The percentage of organic matter and the thickness of the humus layer are of course of great significance in the moisture supply of agricultural crops.

M. L. 't Hart (3) emphasizes the importance of the organic matter content of the turf for the production capacity of permanent grassland on sandy and clayey soils. In his opinion the highest yields are obtained with an organic matter content of the turf of 12-16%. With lower contents the water supply is often unsatisfactory, while higher contents point to insufficient drainage. However, the fact that satisfactory grass yields are obtained on peaty soils, proves that a high organic matter content does not necessarily prevent grassland from being highly productive. 't Hart finally points out that the formation of a humus layer is of the greatest importance for a successful creation of permanent grassland. On sandy soils an organic matter accretion of more than 2,000 kilograms per hectare annually was found after the seeding of the grassland.

It is well known that a regular supply of organic matter in its microbiological decomposition exercises a favourable influence on the soil structure. American, Russian, and British investigators have collected many details in this respect. The crops themselves to a large extent provide the soil with this organic matter by their root development. M. A. J. Goedewaagen (4) has made extensive investigations on the subject in this country. The amount of roots of cereals (there are great differences in different kinds) is nearly 2,500 kilograms per hectare with a topsoil of 20 centimetres (roots and stubbles together). The root yield of potatoes and sugar-beets is much less, i.e., no more than $\frac{1}{4}$ of the root and stubble amount in cereals. Under Dutch conditions this means that per hectare on arable land approximately 2,000 kilograms organic matter are added to the topsoil through root development and the stubbles of main crops.

P. K. Peerlkamp (5) estimated with the aid of laboratory data from abroad the amount of organic matter that is necessary for the maintenance of the soil structure under Dutch conditions and found the annual amount to be equal to that of the roots and stubbles of a cereal. Organic matter must be added in the case of the crop rotation now practised and if the existing soil structure is to be improved. Farm-yard manure is next to the roots of the crops still the most important source of organic matter in the Netherlands. On an average 700 kilograms organic matter per hectare is added to arable land in this form (there are arable districts where no farm-yard manure is employed). Green-manuring ranks after farm-yard manure in importance.

J. Kortleven (6) studied these conclusions and other data and found that in this country too little organic manure is employed. There are several ways to supply the deficiency, e.g., existing town-refuse compost industries may be extended (at present only a small percentage of the town-refuse is used for agricultural purposes); straw may be ploughed in, and green manuring and ley farming may be more extensively practised according to the particular district concerned. The ploughing up of temporary grassland results in a considerable amount of organic matter in the topsoil. Goedewaagen found the amount of roots and stubbles in grassland to be 6-7,000 kilograms. To this is added the above-mentioned accretion of organic matter after seeding, so that in two years' leys the amount of organic matter may be fixed at more than 10,000 kilograms per hectare.

Of course, these estimates are further studied both in the field and in the laboratory. Experimental fields have been laid out where the effect of the intensity of organic matter supply on soil and silo fertility is ascertained. Experiments are also made on farms. Numerous experiments are made to determine the

significance of town-refuse and different methods are tested, e.g., addition after compost-making, addition after pounding in a fresh condition, the mixing with the topsoil, superficial dressing, etc. The conversion of town-refuse into compost is being practised to an increasing extent.

For the sake of completeness the investigation of J. Hudig and N. H. Sieuwerts van Reesema (7) may be mentioned, who studied the possibility of preparing an artificial humus of great stability which might bring about a more permanent improvement of the soil structure. Many experiments were made, which were reported upon by J. Kortleven (8). However, owing to the Second World War a satisfactory composition of the product proved to be impossible, and field-trials were unsuccessful for the same reason. Investigations have been started again and are in full progress.

There are various signs which show that the structure of the soil leaves much to be desired in many cases. Wind erosion and water erosion also occur in the Netherlands, although water erosion is less disastrous than in some other countries. Several agricultural advisers emphasize the importance of organic manuring in order to raise the production level.

P. K. Peerlkamp (9) investigated numerous soil samples by means of a wet aggregate analysis for their aggregate formation. Fig. 1 and Fig. 2 show his results

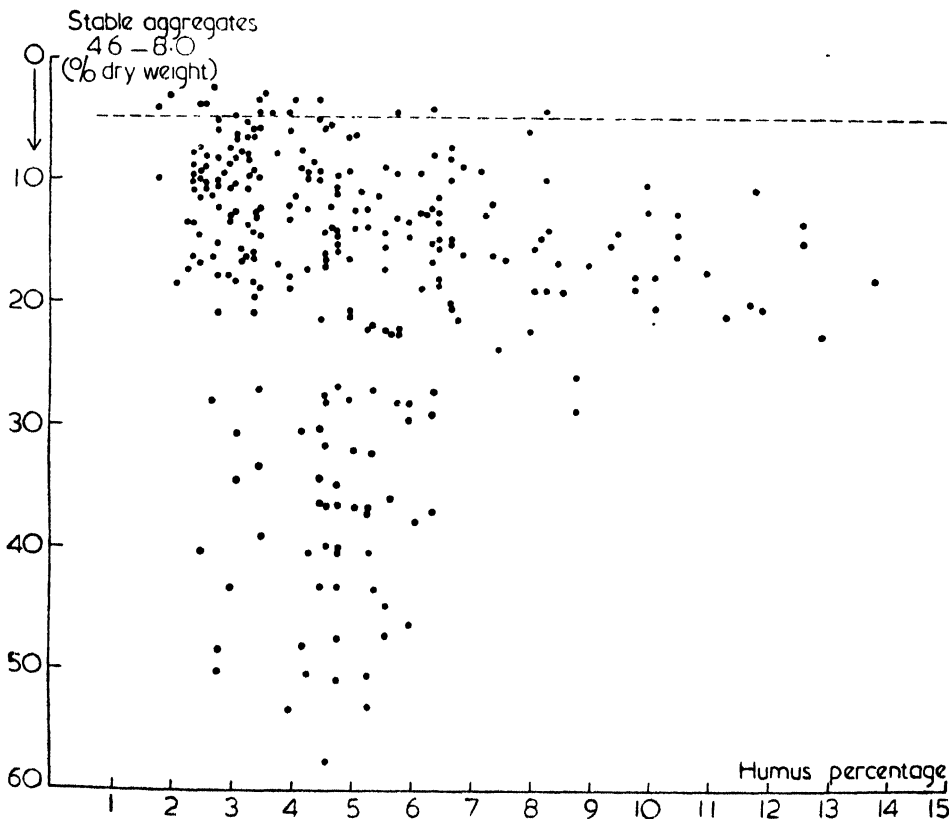


FIG. 1. Soil structure as measured by the percentage of water stable aggregates with sizes between 4.6 and 8.0 mm. (the smaller this fraction the better the structure) plotted against humus content for the top layer of 309 fields on clay soils (clay content $>40\%$ fraction $<16\mu$). Arable land.

The hatched line parallel to the abscissa is assumed for the 'ideal' structure.

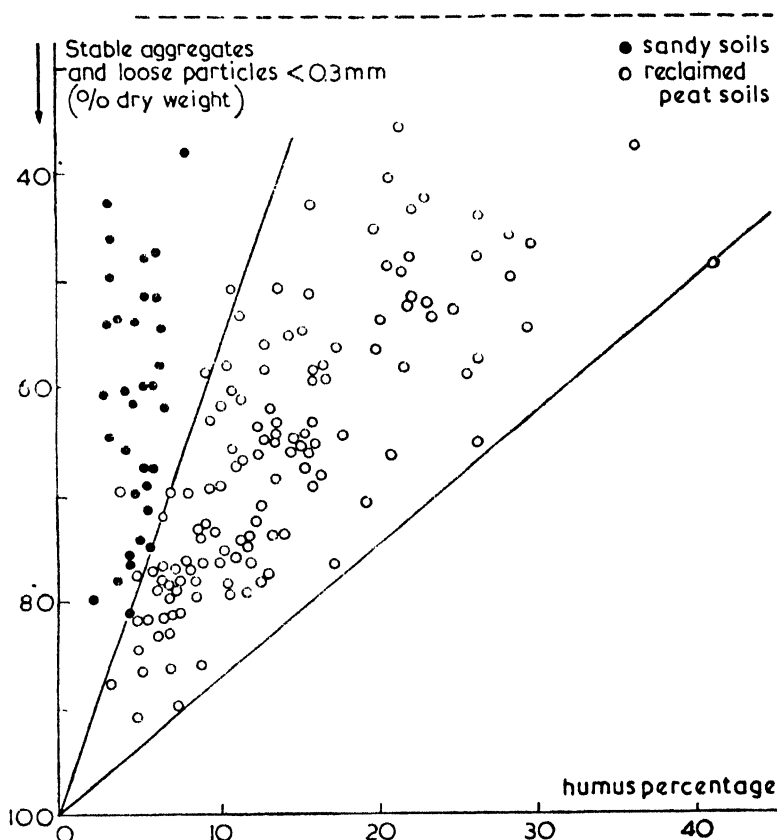


FIG. 2. Soil structure as measured by the wet sieving fraction <0.3 mm. (the smaller this fraction the better the structure) plotted against humus content for the top layer of 37 fields on sandy soils (dots) and 134 fields on reclaimed peat soils (circles). Arable land.
The hatched line parallel to the abscissa is assumed for the 'ideal' structure.

in dependence on the organic matter content of the soil. The broken line parallel to the abscissa shows the optimum structure as it was found according to provisional indications. Two conclusions have been drawn, viz., that with the same organic matter content a series of aggregations may occur and secondly that only a small percentage of the soils come up to the requirements as to high standards of soil structure.

Not only are standards for the soil structure fixed in the laboratory, but also visual methods are applied in the field. Th. J. Ferrari (10) applied the latter method to a series of experimental fields in a clayey district in the Netherlands. Fig. 3 and Fig. 4 clearly show the relation between soil structure and potato yields. It is remarkable that with an optimum nitrogen dressing the influence of the soil structure is more prominent than in plots where no nitrogen has been added. It appears that these results are very much dependent on the weather conditions in a particular year. The above results were found in 1947, whereas in 1948 in the same fields little influence of the structure was observed. This was corroborated by a soil fertility analysis carried out by Ferrari (11) in another clayey district, when the influence and interactions of many factors according to the multifactor analysis were studied.

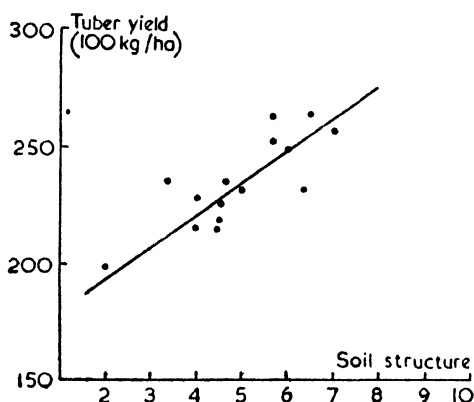


FIG. 3. The relation between the soil structure (determined by a visual method) and the yield of potatoes on plots not manured with nitrogen. Old arable land on clay.

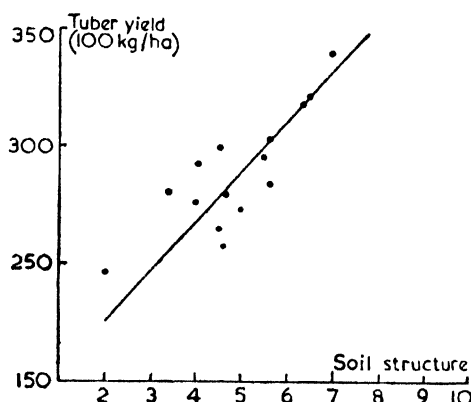


FIG. 4. The relation between the soil structure (determined by a visual method) and the maximum yield of potatoes. Old arable land on clay.

The addition of organic manures not only affects the aggregate condition, i.e., air and soil conditions in the soil, but probably also causes changes of secondary importance. Lack of space prevents us from discussing the significance of many plant nutrients which may be found in organic manures. The nitrogen conditions in the soil and nitrogen supply for crops may be drastically influenced by them. We wonder to what extent the nitrogen gradually becoming available from organic manure, besides quick-acting nitrogen from fertilizers, can have a favourable influence on production. P. G. Meyers (12) and W. A. Bosma (13) obtained data about a similar increase of the fertility level.

In his investigation in 1947, Ferrari found an important relation between the soil structure and the amount of nitrogen from fertilizers needed to obtain a maximum potato yield (Fig. 5). It should be noted that the differences in soil structure

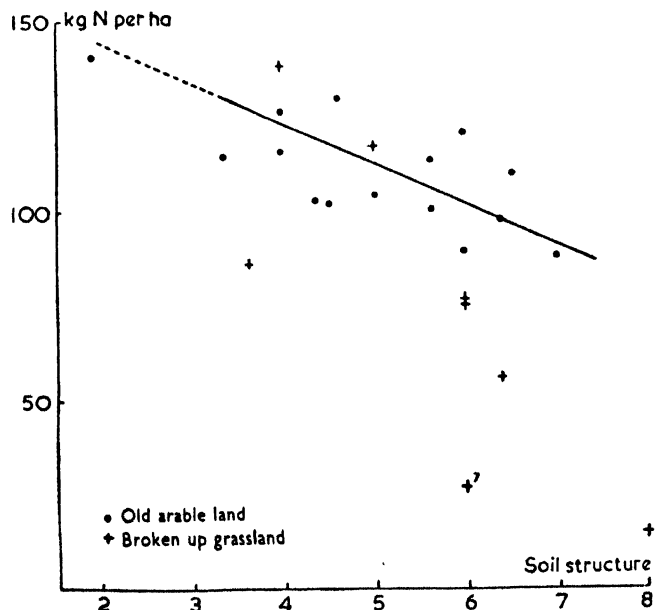


FIG. 5. The relation between the soil structure (determined by a visual method) and the quantity of nitrogen, which is needed to obtain maximal yields of potatoes.

were not deliberately obtained by changing the composition of the organic manure, but were accidentally found in the experimental fields. Ferrari was especially struck by the low amount of nitrogen needed with a good soil structure to obtain a maximum yield. On the ground of analyses of potato and potato-tops he thinks it possible that there has been a considerable nitrogen fixation from the air to the amount of 60 kilograms per hectare. This amount corresponds with the N-fixation which was found by J. G. Maschhaupt (1) in his lysimeter investigation. Several investigators who attended the Fourth International Congress of Soil Science in Amsterdam were surprised at Maschhaupt's results in view of microbiological considerations. Maschhaupt is of opinion that lysimeter investigations may contribute much to the solution of the organic matter problem.

We get the impression that the improvement of the soil structure and an increased use of organic manures will have a favourable influence on the average production level of arable land. It is as yet impossible to express this influence quantitatively. In the above report for the U.N.O. Conference 't Hart estimated for permanent grassland an increase in production of 5%, being the average for the whole area under grass (1,300,000 hectares grassland against 1,000,000 hectares arable land) if farm-yard manure and compost are more intensively employed.

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• SOIL FERTILITY AND AMINO ACID SYNTHESIS BY PLANTS.¹

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(Communicated by Prof. N. R. Dhar, F.N.I.)

Soil science has the responsibility not only of testing the soil for ample supplies of all essential elements, but also of determining the nutritional services of the soil-borne ions as (a criteria) of the soil treatments it undertakes. Of the many synthetic plant products of nutritional value, protein presents itself for first consideration in that it (or its constituents) is essential for growth and reproduction. Previous studies indicate that the common Kjeldahl procedure for measuring total nitrogen is inadequate for determining protein in forages. (Sheldon, Blue and Albrecht, 1948). General diversity of amino acids in legume hays according to soil types and treatments, including the trace elements, promoted further study of the function of the soil-borne plant nutrients as they function in the biosynthesis of these vital substances. Blue, Sheldon and Albrecht (1948), and Tisdale *et al.* (1950) showed that the methionine and cystine contents of alfalfa were influenced by the supply of the sulfate ion. The extension of this work to a survey of wider ranges of soil conditions and the resulting concentrations of the amino acids in more forages should establish the basic nature of these findings. One may, however, anticipate that the supply of any element serving in a catalytic or structural capacity, either as an activator or in a prosthetic group of the enzymes involved in the biosynthetic conversion of the carbohydrates, may produce marked variation in the resulting amino acid array within the plant leaf. The studies here reported, were carried out on well-defined media as well as on natural soils in order to measure some amino acid output by plants in relation to some elements of soil fertility.

In addition to studying the influence of the soil-borne elements upon the amino acid composition of certain forages, it seemed important to establish the amino acid values for these commonly used in pasture systems. Alfalfa and soybeans, were grown in the greenhouse using both the sand-solution cultures, and the colloidal clay techniques. Korean lespedeza, barley, Sudan grass, oats, bluegrass, alfalfa, wheat, rye, sweet clover, ladino clover, and red clover were grown under field conditions with a wide assortment of soil types representing a wide range of soil fertility. The range in the fertility level of these soils was further increased by applying fertilizers.

Using a mixture of Gila and Putnam clays, soybeans were grown by Dr. Donald Brown of Fayetteville, Arkansas, to which Rio Grande irrigation water or a nutrient solution was added. The exchange complex of these cultures was previously reported (Brown and Albrecht, 1947). Soybeans were also grown by Hall C. Turley on dialized colloidal clay and silt mineral mixtures of Wyomingite, and glauconitic dolomite.

Alfalfa, lespedeza, barley, oats, rye, Sudan grass, sweet and ladino clovers were grown on soils of the Prairie Region of South-west Missouri. Alfalfa and barley samples were taken at random (a) where there was no soil treatment, (b) where trace elements or magnesium sulphate or (c) where a mixture of these was offered.

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Other soil treatments, such as, limestone, superphosphate, and rock phosphate were also used. A bluegrass pasture on the Putnam silt loam was treated with limestone, superphosphate, and these plus potash.

Nine of the ten amino acids, essential for the white rat were determined by using the microbiological method of Stokes and Gunness (1945, 1950). The total nitrogen was determined by the Kjeldahl-Gunning-Arnold method as modified by Murneek and Heinze (1937). Van Slyke determinations of nitrogen were made by means of the macro-type deamination apparatus in the usual manner.

SULPHUR AND THE SYNTHESIS OF METHIONINE.

Because much of the sulphur in the plant is thought to occur as a constituent of protein, the amount of sulphur offered to it might reflect itself in the resulting sulphur-containing amino acids, if the needs for the other elements have been met. The methionine assay of alfalfa and soybean hays suggested that the sulphur offered in the growth medium influenced the concentration of this amino acid in the forage as shown in Table 2. Maximum production of methionine occurred when the plants received 64 to 95 p.p.m. of sulphur in the solution.

EXPERIMENTAL DETAILS.

The plants produced in the greenhouse were seeded in two-gallon pots containing white quartz sand. This had previously been leached with concentrated hydrochloric acid and washed repeatedly until the test for chlorides was negative. The nutrient solution (given in Table 1) was applied except where one element at a time was first omitted and then added as increments to give the desired treatment. During the growth of the plant an attempt was made to keep light, water, humidity, temperature and other environmental factors at optimum levels. The nutrients were added each week during the early stages of growth and more frequently as the plants approached maturity. Before a new supply of nutrients was added, the pots were leached with distilled water in order to keep the nutrient supply at the appropriate level. When the plants were in full bloom the above ground portions were harvested and dried in a forced-draft oven at 60° to 65° C. Using the above technique, soybeans were grown on varying levels of magnesium, manganese, boron, sulphur, and iron. Alfalfa was grown on divergent levels of manganese, boron, sulphur, iron and potassium.

TABLE 1.

Composition of Nutrient Solution used in Quartz Sand Cultures.

Element.				Amount in Full Nutrient (p.p.m.)
K	..	..	..	547.0
Ca	..	..	..	400.0
Mg	..	..	..	96.0
N	..	..	..	25.0
P	..	..	..	124.0
S	..	..	..	128.0
Fe	..	..	..	34.0
Mn	..	..	..	1.1
B	..	..	..	1.1

TABLE 2.

Methionine Concentration in Alfalfa and Soybean Hays according to the amounts of Sulphur offered in the Nutrient Solution.

Sulphur offered (p.p.m.)	Alfalfa (mg./gm.)	Soybeans (mg./gm.)
0	1.96	2.67
16	4.50	3.08
32	5.01	3.56
64	5.37	..
96	4.61	6.41
128	2.70	5.90

In a field study of a transitional soil in the South-west Prairie region of Missouri, applications of magnesium sulphate to the soil were found to increase the methionine content of the alfalfa. When barnyard manure was added to the soil along with the sulphur, even greater increases were evident, as indicated in Table 3.

TABLE 3.

Methionine Concentration (mg./gm.) in Alfalfa Hay according to Sulphur applied to the soil.

Treatment.	Methionine at different dates.		
	6/24/48	7/31/48	4/11/49
None	3.10	3.21	2.91
100 lbs./a. MgSO ₄	3.41	3.64	5.87*

* 10 tons per acre of barnyard manure applied.

In an effort to substantiate further these general findings, flowers of sulphur, at the rate of 200 pounds per acre, were applied to an adjoining field where the phosphate requirement had previously been met by the addition of 1,000 pounds of rock phosphate per acre. This sulphur treatment almost doubled the methionine concentration in the Sudan grass while the total nitrogen increased only slightly, as shown in Table 4. Further application of sulphur in the form of magnesium sulphate depressed the methionine yield per unit weight and the nitrogen content.

TABLE 4.

Methionine Concentration in Sudan Grass According to Sulphur Applied to the Soil.

Treatment.	Total N (%)	Methionine (mg./gm.)
1. No sulphur	2.20	2.04
2. 200 lbs./a. sulphur	2.44	4.06
3. Same as 2 plus 100 lbs./a. MgSO ₄	1.96	1.53

SOIL FERTILITY AND THE SYNTHESIS OF TRYPTOPHANE.

Indol-3-acetic acid has frequently been associated with the boron supply from the soil. There was the suggestion, in the data in Table 5, of a possible relation between this element and the concentration of the indol amino acid, or tryptophane,

in both alfalfa and soybean hays. Even though the enzymatic function of boron remains quite obscure, these data substantiate the conclusions of Briggs, namely, that an interruption of the immediate synthetic processes just prior to protein formation occurs when boron is in low supply.

TABLE 5.

*Tryptophane Concentrations in Alfalfa and Soybean Hays according to the amounts of Boron offered in Nutrient Solution.**

Soybean Hay.		Alfalfa Hay.	
Boron offered (p.p.m.)	Tryptophane (mg./gm.)	Boron offered (p.p.m.)	Tryptophane (mg./gm.)
0	1.38	0	1.27
0.27	1.89	0.22	1.36
1.08	3.10	0.44	2.17
..	..	1.08	2.55

* Composition of Nutrient Solution given in Table 1.

In an effort to determine the magnitude of the synthesis of tryptophane by the plants when the elements commonly supplied by the soil are in low amounts, magnesium, boron, manganese, sulphur, iron, calcium and phosphorus were withheld from the growth medium. The results of these modifications of the plant environment, recorded in Table 6, show the pronounced variation in this essential amino acid according to the corresponding variation of these elements of soil fertility.

TABLE 6.

Tryptophane Concentrations in Alfalfa, Soybean, and Redtop Hays according to the Inorganic Nutrients in the Substrates.

Plant.	Treatment.	Tryptophane (mg./gm.)
Soybeans†	Mg withheld ..	1.80
Soybeans†	B withheld ..	1.89
Soybeans†	Full Nutrient ..	3.10
Soybeans†	Mn withheld ..	1.93
Soybeans†	B	0.57
Soybeans†	Fe	1.76
Soybeans†	Full Nutrient ..	2.10
Soybeans*	Wyomingite ..	0.47—0.50
Soybeans*	Glauconitic Dolomite ..	0.66—0.90
Soybeans*	Ex Mg on clay ..	1.06—1.09
Alfalfa†	Mn withheld ..	1.47
Alfalfa†	B	1.15
Alfalfa†	S	2.64
Alfalfa†	Fe	1.74
Alfalfa†	Full Nutrient ..	2.80
Redtop*	High P, High Ca ..	2.65
Redtop*	High P, Med. Ca ..	2.21
Redtop*	High P, Low Ca ..	2.09
Redtop*	Med. P, High Ca ..	2.38
Redtop*	Med. P, Med. Ca ..	1.88
Redtop*	Med. P, Low Ca ..	1.38

† Grown on Nutrient Solution given in Table 1.

* Grown on Colloidal Clay.

In studies of some magnesium minerals from which this element could be weathered at varying rates by the acid colloidal clay, the tryptophane content was lowered according to the magnesium made available from that reaction. The concentration of this amino acid in the case where Wyomingite was offered was only one-half the value of that where the magnesium was readily exchangeable on the clay. Magnesium from the dolomite was more available and expressed itself through increased synthesis of tryptophane by the plant. These data carry the suggestion that either less carbohydrate was built by photo-synthesis or less was respired to yield a critical linkage in the tryptophane molecule. The enzymatic formation of the indol ring could require magnesium as the activating cation at some stage of its synthesis.

In a general fertility study of the calcium-rich Gila clay, with its high exchange capacity and free carbonates, marked increases in propein synthesis would not be expected when additional calcium, magnesium, potassium and sodium are offered to the plant. Yet, more arginine, threonine and valine were produced when the Rio Grande irrigation water containing these elements was applied.

TABLE 7.

Tryptophane, Valine and Basic Amino Acids in Soybean Hays according to Addition of Nitrogen and Phosphorus to Natural Gila Clay. (mg./gm.).

Medium.	Arginine.	Histidine.	Lysine.	Valine.	Threonine.	Sum of Basic Amino Acids.*
Gila Clay ..	5.7	3.7	11.8	8.4	4.3	21.2
Gila Clay plus irrigation water ..	6.5	4.1	11.3	9.1	4.9	21.9
Gila Clay plus solution containing N and P	8.4	4.7	12.2	10.9	7.8	24.3

* The sum of the histidine, arginine and lysine.

That even more of those amino acids were built where a nutrient solution containing nitrogen and phosphorus was offered the soybean plants is indicated by the evidence in Table 7. Since nitrogen is a constituent of these molecules, and since phosphorus is required to convert the simple carbohydrates into their organic acid precursors, an increase in any or all of the amino acids could be expected. There were general increases in arginine, threonine, and valine. In view of the leadership rôle commonly assigned to the basic amino acids, namely, arginine, histidine, and lysine, in the theories of protein structure, one might expect these compounds to be synthesized in a constant ratio in any given plant species. Only arginine showed a striking increase.

GENERAL VARIATIONS IN NITROGEN FRACTIONS WITHIN SPECIES.

Considerable controversy has existed as to whether the amino acid contents of a plant, i.e., the free amino acids plus those hydrolyzed from the proteins, may be modified by alterations of the plant environment and particularly whether or not these concentrations vary proportionally with the total nitrogen. Maximal and minimal values of the nitrogen fractions and their ratios for different species have been assembled in Table 8. Those acids having simpler structures gave ratios corresponding to those of the percentages of nitrogen. In the amino acids histidine, tryptophane, arginine and methionine, the ratios were considerably different from

TABLE 8.

Maximal and Minimal Concentrations of the Amino Acids arranged by Plant Species with the ratios of the former to the latter values.

Plant species.	Maximum or Minimum.	% N.	Valine.	Leucine.	Isoleucine.	Threonine.	Tryptophane	Histidine.	Lysine.	Arginine.	Methionine.
<i>Alfalfa</i>	Maximal	5.53	27.8	18.7	39.4	13.5	3.91	9.9	25.8	13.8	6.51
	Minimal	1.93	9.4	6.5	11.0	4.8	0.84	2.3	7.0	2.2	trace
	Max./Min.	2.86	2.96	2.88	3.58	2.82	4.65	4.3	3.69	6.28	..
<i>Soy-beans</i>	Maximal	5.04	20.3	26.6	39.1	16.0	3.35	11.3	39.5	10.4	5.90
	Minimal	1.11	8.1	9.2	10.9	3.5	0.32	3.5	10.2	2.4	1.83
	Max./Min.	4.54	2.51	2.89	3.59	4.57	10.48	3.23	3.88	4.33	3.22
<i>Korean Lespedeza</i>	Maximal	3.60	20.5	19.3	28.2	11.8	3.19	8.6	28.8	9.4	3.31
	Minimal	1.98	10.2	8.3	16.7	5.3	0.79	2.1	9.9	1.6	0.90
	Max./Min.	1.82	2.07	2.33	1.69	2.23	4.04	4.1	2.91	5.88	3.68
<i>Sudan grass</i>	Maximal	2.78	11.9	11.9	..	7.5	2.42	3.1	..	3.7	4.06
	Minimal	1.71	8.6	8.6	..	5.5	0.88	2.3	..	1.9	1.53
	Max./Min.	1.62	1.43	1.39	..	1.36	2.75	1.35	..	1.95	2.64
<i>Barley</i>	Maximal	5.96	18.9	20.3	14.4	12.1	3.58	10.2	22.0	5.1	5.40
	Minimal	4.24	12.2	12.3	8.9	6.8	1.50	5.5	9.8	2.7	2.64
	Max./Min.	1.41	1.55	1.65	1.62	1.78	2.39	1.85	2.24	1.89	2.05
<i>Blue-grass</i>	Maximal	4.05	19.8	19.6	36.2	16.4	2.41	8.1	28.3	7.6	4.69
	Minimal	1.36	4.7	5.6	12.3	3.6	0.76	2.8	6.2	3.4	1.26
	Max./Min.	2.98	4.22	3.50	2.94	4.56	3.17	2.89	4.57	2.23	3.72

the ratio of the total nitrogen. In view of their more complex linkages, their synthesis by modification of the sugar chain should be more involved.

Legumes are generally considered to contain small quantities of methionine, yet large quantities were found in some of the legume forages. The ratios of the maximal to minimal concentrations of methionine were, in general, larger for the legumes than for the non-legumes. This points directly to the fallacy of referring to a species of plant as being low in some particular constituent unless plants grown under a wide variety of soil conditions are examined.

DISCUSSION.

In the physiology of an organism, we have regularly recognized the necessity of considering the inorganic environment in attempts to explain performances by it. The measurement of the delivery by the soil of the inorganic elements constituting the ash of the plant material, as the soil's only contribution to the quality of the crop, has been an unfortunate criterion of the importance of the soil factor of environment. This little appreciation of the soil has persisted even when the ecological array of plant species suggests that plants must be of diverse organic quality as they evolve on the various and diverse soils. Efforts to evaluate the protein status of a crop by the common total nitrogen techniques fail to present the true picture of forage protein. Since the food value of the forage depends upon the complete list of the amino acids and not on the total nitrogen *per se*, we need to adopt organic assays as newer criteria by which to measure the service of the soil in plant production for good nutrition.

That the quality of forage protein can be altered by any factor of environment is of utmost significance. Whether the protoplasmic protein or merely the free amino acids in the plant sap is modified is of little significance from a standpoint of nutritional values.

Plants stand in the cycle of nutrition as enzymatic factories wherein sufficient quantities of the essential amino acids are made according to the soil. Diagnostic techniques using any biological assay of soil fertility must ultimately measure molecules both organic and inorganic, as the reactants in biosynthesis. The *status quo* of the complete biotic pyramid could thus be viewed as merely the union of colloidal particles having enzymatic specificity to yield the numerous protoplasmic components according to the fertility of the soil on which the entire pyramid rests.

To sum up, we now have suggestive evidence from the relative effects of phosphorus, sulphur, nitrogen, boron, magnesium, iron, and manganese on the amino acid array in the organic composition of alfalfa, soybeans, bluegrass, lespedeza, redtop and Sudan grass hays, that the soil serves in the control of the nutritional quality of forages. This is substantiated particularly by considerations of the elements sulphur and boron in the formation of methionine and tryptophane respectively. A single species of plant may vary widely with respect to its amino acid content. These conclusions are in no way contradictory to the general experience of plant physiologists who have worked with the processes of biosynthesis. Indeed, the fairly close relation between our experiments and the findings of the enzymologists is entirely consistent with the present view.

SUMMARY.

A microbiological assay for nine of the ten amino acids required by the white rat in alfalfa (*Medicago sativa*), soybeans (*Soja max*), redtop (*Agrostis stolonifera major*), and Sudan grass (*Sorghum vulgare* var *Sudanese*) showed that these organic substances of particular food values varied widely according to the inorganic composition of the substrate upon which the plants were grown. The synthesis of methionine was inhibited when sulphur was withheld from the solution or was in low supply in the soil. Application of flowers of sulphur doubled the methionine concentration in the Sudan grass.

The formation tryptophane was found to be proportional to the available boron when this anion was the limiting element in the culture solution. Tryptophane synthesis was decreased when magnesium, boron, manganese and iron were withheld from nutrient solutions offered alfalfa and soybeans.

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ORGANIC *VERSUS* INORGANIC MANURES IN LAND IMPROVEMENT AND CROP PRODUCTION.

(From the Department of Agriculture, Madras.)

(Communicated by Prof. N. R. Dhar, D.Sc., F.N.I.)

Widespread use of inorganic fertilizers in recent years and the high esteem in which they are held today by progressive farmers all over the world as an essential adjunct for increased crop production have, to a certain extent, lessened the severity of attacks that have been made on the practice of using artificial fertilizers. They have also served to allay the fears in the minds of farmers that the use of inorganic fertilizers will ruin their land. The presentation of manurial problems as a controversy concerned with organic manures *versus* mineral fertilizers is unfortunate and, as aptly described by Dr. Salisbury, is due to confusion of thought and complete failure to apprehend either the facts or the problem.

In India, the only manure the soils were receiving from time immemorial was farmyard manure and to a much smaller extent green manure for paddy besides such stubbles and crop residues that may naturally be left in the field when the crop is removed.

Under the tropical conditions existing in this country, these were rapidly oxidized by the soil micro-organisms which restored, more or less, the natural fertility of the land by fixing the much-needed nitrogen from the atmosphere. The advantages of using such organic manures in improving the physical condition of the soil, promoting good tilth and increasing the water-holding capacity and aeration were well known and the efforts of the Department of Agriculture, Madras, were in the early periods primarily directed towards dissemination of knowledge in the better methods of conservation and utilization of cattle manure, application of green manures, and composts obtained from farm wastes. But it was soon realized that the amount of these forms of manure available for application to lands was quite inadequate to replace the loss of plant nutrients occurring in the soil through continuous cropping, leaching and erosion and that it was not possible to economically continue crop production without having recourse to other sources of plant nutrients.

The position as regards the manuring of land in the Madras State can well be understood when it is seen that out of an annual production of 20 million tons of cattle manure, barely half of this quantity becomes available for application to over 35 million acres of cropped area, the rest being burnt as fuel. It is estimated that even if all the sources of organic manures like farmyard manure, oil cakes, compost, etc., are fully mobilized, it would be just enough to manure only about 15 million acres.

In actual practice, however, the application of organic manures is confined mainly to garden crops and paddy, the bulk of the dry areas receiving none or only a scanty supply. The rôle of inorganic fertilizers in South Indian Agriculture is mainly supplementary, intended to make good the deficiency of plant nutrients in the soil. There have been no instances where applications of artificial manures have brought about adverse effects on the soil.

The opposition to the use of fertilizers was mainly based on the supposed ill-effects that the use of these fertilizers bring on the land and on the human beings and animals consuming the produce grown on it. Some of the alleged evil effects attributed to the use of mineral fertilizers are (a) that it adversely affects the

physical, chemical and biological conditions of the soil, (b) it accelerates soil erosion, and (c) it injures the quality of the produce and lowers the ability of the crops to resist pests and diseases. Further, it is also alleged that many of the diseases prevalent now among animals and human beings are attributable to the consumption of produce grown on lands fertilized with artificials. Dr. Ogg, Director, Rothamsted Experimental Station, Harpenden, England, has examined the various allegations made by the opponents of mineral fertilizers and quoting extensively from results obtained from long term experiments carried out at Rothamsted, has categorically refuted these allegations as baseless since they lacked experimental evidence. He is of the opinion that organic manures and mineral fertilizers have their own uses and should be regarded as complementary.

Various experiments have been carried out in Madras State for over a period of nearly 40 years to study the effect of fertilizers, with and without organics, at various centres on different crops. Most of these experiments with the two forms of manures were not exclusively designed to assess their individual merits, but their application formed merely the variants in the scheme of comprehensive manurial trials comprising different treatments. From these trials sufficient data are available to judge the individual performances of organic and inorganic forms of manure and in the light of these findings, it is possible to examine some of the allegations. But the permanent manurial experiments at the Agricultural College and Research Institute, Coimbatore, have been designed solely with this objective.

Effects on the Soil.

Results of analysis of soils from permanent manurial plots receiving treatments like 'no manure', farm-yard manure and artificials (N plus K plus P) for various physical properties like pore space, water-holding capacity, apparent specific gravity, volume expansion, etc., have not given any definite indication that the physical condition of the soils receiving full complement of artificials are seriously impaired. The moisture-holding capacity and volume expansion of soils from plots receiving farmyard manure and 'no manure' are noted to be slightly higher than that of plot receiving artificials (N plus K plus P) only. Though the primary function of fertilizers is to supply plant nutrients to growing crops, it is often noticed that application of fertilizers often brings about marked changes in the characteristics of the soil which may be beneficial or detrimental depending upon the soil and the fertilizers. A careful consideration of the physical characteristics of the soil and selection of a proper fertilizer would often prevent the adverse effects on soils resulting from fertilizer application. Experiments conducted in the Agricultural Research Stations have shown that sodium nitrate as a source of nitrogen is inferior to ammonium sulphate or green manure for South Indian soils. It was also found to have harmful effects on the physical condition of soil and soil reaction. Ammonium sulphate under similar conditions has performed exceedingly well. Crops raised in permanent manurial plots where fertilizers were annually applied for the past forty years continuously are still giving high yields showing that application of artificials have had no deleterious effect on the physical condition of the soil.

In the case of Old Permanent Manurial Experiments at Coimbatore a comparison of the chemical analysis of the soils of the experimental plots, carried out at an interval of 23 years, has shown that continuous application of artificials has not in any way affected the chemical composition of the soil. On the other hand, mineral phosphates have greatly enhanced the total phosphoric acid content of the soil, whereas similar effect was not noticed in the case of soil from the plots receiving only organic manures.

A comparison of the bacterial counts of soils from plots receiving 'no manure', organic manure and artificial manures, has indicated that the bacterial population

is higher in plots receiving artificial manures than the 'no manure' ones though not as high as that of organic manure plots which might be expected since bacteria are intimately concerned with the process of decomposition of organic matter. This comparison will show that the application of inorganic manures is not detrimental to the growth of organisms in the soil. The bacterial counts and the microbial activity of the differentially manured plots are furnished in Table I.

No experimental evidence is available in this Province as regards the effect of fertilizers on the erodability of the soil.

Effect on Yield.

The crop-war statistical interpretation of the yield data from the Permanent Manurial Experiments at Coimbatore covering over a number of years shows in general that cattle manure is not definitely superior to artificials and the statements that artificials show distinct superiority over farmyard manure in the earlier years of application and that in later years farmyard manure asserts itself in contributing to greater yields (Dr. B. Viswanath—*Indian Journal of Agri. Sci.*, Vol. I, 1931, p. 497) is not substantiated by the consolidated statistical analysis of crops raised during the past 40 years. Table II gives statistical interpretation of the yield data from the Permanent Manurial Plots of Coimbatore.

It will be interesting to note that the trend of results obtained with organics and inorganics in the Permanent Manurials, appear to be similar as at Rothamsted and elsewhere. It has been observed by E. J. Russell (*Imp. Bur. Soil Sci. Tech. Comm.*, 40, 1940), in his review of the results of the Rothamsted and Woburn experiments during the past nearly one century, that the average yields from the organic (farmyard manure) and inorganic manured plots (N plus K plus P) are practically the same. The advantages claimed for farmyard manure are:

- (a) Seasonal fluctuations in yield are smaller in farmyard manure plots than in the mineral fertilizer ones; and
- (b) Deteriorations of yield is slightly lower in farmyard manure plots than in the mineral manure series.

Experiments carried out in other parts of the State have shown that application of inorganic nitrogen was as good on the crop yield as organic N and in a few cases, it was found even superior in areas where pronounced N deficiency was noticed. The results of experiments conducted in different centres are presented in Table III.

Effect on the composition of the crop.

Chemical analysis of the crops raised under different manurial treatments have shown that as regards N and potash there is no significant variation in the composition of the grains grown under any system of manurial treatment. Application of nitrogen and potash has not increased their percentages in the grain, but the most striking difference was noticed in the case of phosphates and that was in favour of the phosphate plots.

Effect on the quality and nutritive value of the produce:

Dr. B. Viswanath in his article 'Food requirements of Crops with reference to South Indian Soils' (*Ind. Jour. Agri. Sci.*, Vol. I, 1931, p. 495) has stated that the seeds obtained from the cattle-manured plots gave a very much better crop than those obtained from plots receiving either mineral manure or no manure. It is further stated that the results of nutritional experiments carried out in association with Lt.-Col. McCarrison had shown that a crop raised with cattle manure possessed better nutritive value than a crop which received only mineral fertilizer. Nutrition experiments carried out by P. V. Ramiah in 1930-31 have indicated that herbage

of cereal crops manured with cattle manure have higher nutritive value than the herbage from control and artificial plots—a result in keeping with work on grains done previously. Conclusive evidence on this aspect of the effects of organic manure is, however, still wanting as no further nutritional experiments were carried out.

Effect on the incidence of pests and diseases.

Dr. Ogg (*Scottish Journal of Agriculture*, Vol. 25, 1946, page 76) has stated that there is no sound evidence regarding the allegation that fertilizers increase the liability of crops to pests and diseases. He has further stated that no difference in the level of infection was noticed in the differentially treated plots. Experiments carried out in the Mycology Section in this State have shown that excessive application of nitrogenous manure either artificials or organics induced increased susceptibility of rice crop to infection by fungi. Though there is some evidence that soil fungi affecting crops might be kept down by application of organic matter, as regards diseases brought about by air-borne fungi, the crop susceptibility does not depend on the nature of manure applied.

Balanced Manuring:

The objects of manuring are to increase crop yields and to maintain the fertility of the soil. The use of organic manures exclusively will not achieve this object, since organic manure like farmyard manure though it possesses many beneficial effects and contains a wide range of nutrients, is still ill-balanced for the most effective use as the sole supplier of nutrient requirements of crops. Farmyard manure contains 0.5 to 1% N, 0.25 to 0.5% P_2O_5 and 0.5 to 1% K_2O depending on the care taken in preservation but only a part of these nutrients is present in a form available to the crop. On this basis, it is calculated that 10 tons of farmyard manure will supply only 5 to 10 lbs. N, 1 to 2 lbs. P_2O_5 and 5 to 10 lbs. of K_2O and hence the application of farmyard manure alone will not be a balanced manure for most crops. The utilization of farmyard manure alone would result in gradual reduction of soil fertility unless other sources of nutrients are made available. Even if all the sources of organic manures are fully exploited it will not be sufficient to meet the demands of the entire cropped area of this State. The introduction of chemical fertilizers which contain high proportion of essential nutrient elements required for crop growth and that too in readily available form, would definitely make substantial contribution in increasing production and in the maintenance of soil fertility. This does not affect in any way the position of organics which must still remain as the primary source of organic matter to the soil.

Fertilizers would enable the organic manure to be applied to a wide acreage while the former would supplement the latter with readily available plant nutrients. The combination of organic and inorganic manures for application to lands has become fairly established in the farming practices not only in this country but also throughout the world. Precise experiments carried out in the Madras State on the effects of applying organic matter in combination with mineral fertilizers, the results of which are presented in Table IV, have indicated (1) better utilization of artificial fertilizers in the presence of organic manures; (2) better availability or utilization of organic manures when combined with inorganics due probably to stimulated activity of the latter; and (3) organic manures have also been found beneficial to the soil in improving its tilth when used continuously in good amounts.

It is incorrect to believe in the exclusive use of any one form of manure—organics or inorganics—and to think that one can be completely replaced by the other. In the present-day context where increased production is the crying need, beliefs and assertions of the superiority of one over the other may well be ignored and in the larger interests of the country, a co-ordinated system of manuring

employing a judicious combination of both organic and mineral manures based on sound scientific principles, should be adopted for the maximisation of food production.

TABLE I.

Bacterial Counts in Old Permanent Manurial Soils.

IRRIGATED CONDITION.				
		No manure.	N + K + P (Artificial).	Cattle manure.
June, 1927	..	790,000	5,000,000	5,100,000
July, 1927	..	2,200,000	3,000,000	5,000,000
August, 1927	..	2,500,000	4,400,000	6,000,000
RAINFED CONDITIONS.				
1947-48	.. ..	1,140,000	1,170,000	1,360,000
1948-49	.. ..	420,000	650,000	640,000

Differences in bacterial count between cattle manure and no manure have narrowed down due to dry conditions and successive monsoon failures.

MICROBIAL ACTIVITY.

		Mgms. of CO ₂ evolved per day in 100 gms. of soil	
		without dextrose.	with dextrose.
1947-48	{ No manure ..	4.60	12.84
	{ N plus K plus P ..	10.83	14.90
	{ Cattle manure ..	14.01	29.18
1948-49	{ No manure ..	7.92	16.15
	{ N plus K plus P ..	15.33	27.19
	{ Cattle manure ..	15.14	15.93

TABLE II.
Old Permanent Manurials.

	Fodder Chulam. 7 crops.	Chulam. 17 crops.	Regi. 15 crops.	Panivaragu. 11 crops.	Wheat. 6 crops.	Cotton. 2 crops.	Gogu. 2 crops.	Cum- bu. 2 crops.	Bengal Gram 1 crop.	Tob- acco 1 crop.
1. No manure	% 4,975 100	% 623 100	% 474 100	% 442 100	% 372 100	% 528 100	% 675 128	% 166.4 128	% 100 100	% 637 637
2. Nitrogen ..	7,645 153.7	690 110.7	552 116.4	526 119.0	514 138.1	446 84.4	775 213	166.4 213	175 475	475
3. N plus K ..	8,312 167.2	715 114.7	601 126.8	483 109.2	536 144.1	505 95.6	675 242	189.0 242	250 437	437
4. N plus P ..	10,645 213.8	1,641 263.4	1,493 314.9	860 194.5	908 244.1	792 150.0	900 337	263.3 337	250 687	687
5. N plus P plus K ..	10,380 208.6	1,665 267.2	1,545 325.9	801 181.2	1,021 271.7	707 133.8	887 328	256.2 328	175 625	625
6. K plus P ..	8,081 162.4	1,401 224.8	1,314 277.2	751 169.9	769 206.9	599 113.4	700 246	192.2 246	125 587	587
7. K ..	7,822 157.4	731 117.3	733 154.6	530 119.9	514 138.1	547 103.6	675 181	141.4 181	100 350	350
8. P ..	7,492 150.6	984 157.9	905 190.9	722 143.3	564 151.6	473 89.6	756 129	100.8 129	50 575	575
9. Cattle manure ..	9,623 193.4	1,693 271.7	1,328 280.1	835 188.9	806 216.6	1,011 191.4	670 367	286.7 367	140 720	720
10. Cattle man- ure (Resi- dual) ..	6,902 138.7	913 162.6	685 144.5	503 113.8	369 99.1	598 113.2	667 229	178.9 229	200 1,191	1,191
Critical difference (1%).	V.H. Sig. 2,321 46.7%	V.H. Sig. 375 60.1%	V.H. Sig. 177 37.3%	V.H. Sig. 193 43.6%	V.H. Sig. 290 77.9%	V.H. Sig. 243 46.0% (C.D. at 5% level).	Not Sig. 124.3 lb.	V.H. Sig. 97.1%		
Fodder Chulam ..	4, 5, 9, 3, 6, 7, 2, 8, 10, 1;		Cholam	.. 9, 5, 4, 6, 8, 10, 7, 3, 2, 1;		Ragi	.. 5, 4, 9, 6, 8, 7, 10, 3, 2, 11			
Panivaragu ..	4, 9, 5, 6, 8, 7, 2, 10, 3, 1;		Wheat	.. 5, 4, 9, 6, 8, 3, 2, 7, 1, 10;		Cotton	.. 9, 4, 5, 6, 10, 7, 1, 3, 8, 2			
Gogu (Fibre) ..	4, 5, 2, 8, 6, 7, 1, 3, 9, 10;		Cumbu	.. 9, 4, 5, 6, 3, 10, 2, 7, 8, 1.						

TABLE II—(Contd.).

New Permanent Manurials.

EASTERN SERIES.

WESTERN SERIES—Basal dressing FYM.

	Cholam. 9 crops.	Ragi. 10 crops.	Panivaragu. 7 crops.	Wheat. 4 crops.	Cholam. 9 crops.	Ragi. 10 crops.	Panivaragu. 7 crops.	Wheat. 4 crops.
1. No manure ..	1,638	1,207	663	658	1,387	1,337	546	874
2. N ..	1,590	1,135	600	635	1,589	1,409	697	913
3. N plus K ..	1,641	1,303	630	759	1,670	1,381	631	893
4. N plus P ..	2,106	1,923	682	936	2,056	2,106	742	932
5. N plus P plus K ..	2,200	1,977	679	880	2,107	2,104	773	829
6. K plus P ..	1,906	1,801	588	719	1,903	1,837	767	740
7. K ..	1,689	1,188	579	728	1,798	1,599	697	739
8. P ..	1,962	1,798	640	810	1,968	1,825	801	724
9. Cattle manure ..	2,072	1,955	768	970	2,184	2,126	827	833
10. Cattle manure (Residual) ..	1,437	1,160	515	830	1,865	1,653	698	773
Significance ..	V.H. Sig. 1%	V.H. Sig.	Not Sig.	Sig. 1%	V.H. Sig.	V.H. Sig.	Not Sig.	Sig. 5%
1% c. diffee. between treat- ment. Means ..	345 lbs.	297		106	238	305		171 lbs. 5% C/D

Cholam ..	..	5, 4, 9, 8, 6, 3, 1, 2, 7, 10	9, 5, 4, 8, 6, 10, 7, 3, 2, 1
Ragi ..	..	5, 9, 4, 6, 8, 3, 1, 7, 10, 2	9, 4, 5, 6, 8, 10, 7, 2, 3, 1
Panivaragu ..	..	9, 4, 5, 1, 8, 3, 2, 6, 7, 10	9, 8, 5, 6, 4, 10, 7, 2, 3, 1
Wheat ..	..	9, 4, 5, 10, 8, 3, 7, 6, 1, 2	4, 2, 3, 1, 9, 5, 10, 6, 7, 8

CONCLUSION: From the results of Old and New Permanent Manurial experiments:

1. In both series the treatment effects fall into two main groups with P and without P. The difference between these two groups is very much more marked than the difference within the respective groups A and B.
(A) With P group—NPK, NP, PK, P and Cattle manure; (B) Without P group—K, NK, N, Cattle manure residual. No manure.
2. In no case has *Cattle manure* proved definitely superior to NPK or even NP but NPK has, in the case of Ragi, given significantly better yields than Cattle manure.
3. It is worth noting that in all four crops cholam, ragi, panivaragu and wheat, the first four highest yields are given by the same treatments, namely, NPK, NP, Cattle manure and PK. In three out of four crops (i.e. except in the case of ragi) the differences found between these four treatments are not significant.
4. In other words the practical effect in crop production is more or less the same irrespective of whether cattle manure is applied or a complete artificial (inorganic) fertilizer is added or only N plus P or K plus P fertilizers are applied.
5. The residual effect of cattle manure is very little and in most cases it is only as good as *no manure*.
6. Nitrogen applications alone are insufficient to improve yields especially grain yields though for fodder cholam, N by itself has given as good yields as CM or NP or NPK.
7. P by itself is able to show an increase in yield over control (No manure) only in the case of ragi and panivaragu. As a rule NP is a better combination than PK though both are greater than no manure.
8. K by itself is ineffective in improving yield more than control.
9. Thus the chief practical recommendation that emerges out of these long continued experiments is:—
(a) Regular applications of cattle manure can give as good yields as can be expected from any other combination of inorganic fertilizer.
(b) For maximum crop production either Cattle manure or NPK is desirable but where otherwise unavoidable NP can also give as good yields as NPK or CM and can therefore be recommended.
(c) Potassic fertilizers are not really essential for the cereal crops studied so far.

TABLE III.
Yield Data for Inorganic and Organic Nitrogenous Manures tried individually.

Locality.	Crop and duration of the trial.	Treatments.	Average yield per acre.	Remarks.
Semalkota	..	Sugar-cane Co. 213 (Duration 3 years.)	Jaggery, in lbs.— (1) 8,698 (2) 7,913 (3) 7,695 (4) 7,376	Ammonium sulphate has given the highest yield.
		Do. do. (4 years).	Cane, Wt. in tons— 38.79 44.16	Ammonium sulphate is the best.
		Sugar-cane (3 years).	Cane, Wt. in lbs.— (1) 53,686 (2) 50,349	Ammonium sulphate has given slightly higher yields than the cake (6.6%).
		Paddy (4 years)	(1) 2,446 lbs (2) 2,081 lbs	Difference between the two treatments negligible but the dosage of green manure is too high.
Palur	(1) AmSO_4 —100 lbs. N. (2) G.N. cake—100 lbs. N.	(A). (1) 2,378 lbs. (2) 2,184 lbs.	No difference in yields between treatments in spite of heavy dose of N as ammonium sulphate.
Manganallur	..	(1) Green leaf—11,250 lbs. (2) AmSO_4 —112 lbs.	(B). (1) 2,271 lbs. (2) 2,272 lbs. (1) 1,860 lbs	Artificial are in no way better than green leaf in spite of their heavy N contents. Cyanamide appears to have a depressing effect.
		Field (A). (1) Green leaf—5,000 lbs (2) AmSO_4 —3 cwts.	(2) 2,074 lbs. (3) 2,004 lbs.	No difference between the two treatments.
		Same as (A)		
		Paddy (duration not specified).	(1) Cyanamide—2 cwts. 40 lbs. N. (2) AmSO_4 —2 cwts. 40 lbs. N. (3) Green leaf—4,000 lbs.	
Aduturai	..	Paddy (3 years)	(1) Nitrate of soda—50 lbs. N. (2) Cattle manure—50 lbs. N.	

TABLE III—(Contd).
Yield Data for Inorganic and Organic Nitrogenous Manures tried individually—(Contd).

Locality.	Crop and duration of the trial.	Treatments.	Average yield per acre.	Remarks.
Aduturai	Paddy (5 years)	(1) Leaf N—50 lbs. N	(1) 2,738 lbs.	No difference between the two treatments.
		(2) Nitrate—50 lbs. N	(2) 2,794 lbs.	
Nanjand	Potato (3 years)	(1) Cattle manure—5 tons.	(1) 18.49 maunds	Cattle manure better than nitrate.
		(2) NaNO_3 —1 cwt.	(2) 16.10 maunds	
Coimbatore Central Farm	Paddy (6 years)	(1) Sodium nitrate—50 lbs N.	(1) 2,763 lbs.	Green manure better than nitrate.
		(2) Green manure—50 lbs. N.	(2) 3,083 lbs.	
Koilpetti	Cotton (3 years)	<i>Yield of Kapas—</i>		Cake far superior to nitrate.
		(1) Neem cake 1,000 lbs.—40 lb. N.	(1) 706 lbs. (100% increase over control).	
		(2) Saltpetre 300 lbs.—40 lbs. N.	(2) 537 lbs. (53% increase over control).	

TABLE IV.
Yield Data for Inorganic and Organic Nitrogenous Manures tried in combination.

Locality.	Crop and duration of trial.	Treatments.	Average yield per acre.	Remarks.
Maruturu	Paddy (2 to 3 years).	(1) AmSO_4 —30 lbs. N.	Gain in lbs.— (1) 1,920 (28% increase over control).	Artificial (AmSO_4) in combination with green leaf has proved best.
		(2) Green leaf 4,000 lbs. (30 lbs. N).	(2) 2,010 (34% increase over control).	
		(3) Green leaf 2,000 lbs.—(15 lbs. N) plus AmSO_4 (15 lbs. N)—Total 30 lbs. N.	(3) 2,160 (44% increase over control).	
Pattambi	Paddy (1 to 3 years).	(1) Green manure—(50 lbs. N).	(1) 2,032—(27% over normal).	Do. do.
		(2) Green manure plus AmSO_4 —(45 lbs. N).	(2) 2,560—(60% over normal).	
Aduthurai	Paddy (4 years)	(1) Green leaf 4,000 lbs. plus g.n. cake 100 lbs.—(30 lbs. N).	(1) 3,137—(25.5% over normal).	Do. do.
		(2) Green leaf 4,000 lbs. plus AmSO_4 50 lbs.—(30 lbs. N).	(2) 3,608—(44% over normal).	
		(3) Green leaf 4,000 lbs. plus g.n. cake 200 lbs.—(45 lbs. N).	(3) 3,447—(38% over normal).	
		(4) Green leaf 4,000 lbs. plus AmSO_4 100 lbs.—(45 lbs. N).	(4) 3,987—(59.5% over normal).	
Coimbatore Central Farm Govt. Agricultural Chemist's Experiments.	Paddy (2 years) Field trial.	(1) AmSO_4 —30 lbs.	(1) 2,373—(14% over control).	Artificial plus green leaf is only slightly better and the result is not so striking as at other stations.
		(2) Green manure 5,000 lbs.—(30 lbs. N).	(2) 2,656—(12% over control).	
		(3) Green manure 10,000 lbs.—(60 lbs. N).	(3) 2,720—(13% over control).	

TABLE IV—(Contd.)
Yield Data for Inorganic and Organic Nitrogenous Manures tried in combination—(Contd.).

Locality.	Crop and duration of trial.	Treatments.	Average yield per acre.	Remarks.
Coimbatore Central Farm Govt. Agricultural Chemist's Experiments.—(Contd.)				
Palur	Paddy (2 years) Field trial.	(4) AmSO_4 —30 lbs. N plus green manure 5,000 lbs. N. (Total N—60 lbs.).	Grain in lbs.— (4) 2,779—(16% over control).	
	Paddy (2 years) Pot culture trials).	Treatments same as above, i.e. as field trials. (1) (2) (3) (4)	Average Grain Wt. in gms. A. O.P.M. B. D. Block Soil. 3-50 9-45 6-72 9-25 7-20 7-79 8-28 9-65 Yield of canes in tons per acre— (1) 14-80 .. (2) 16-36 .. (3) 19-49 .. (4) 20-73 ..	Results slightly in favour of artificials (in AmSO_4) in combination with green leaf. (1) Progressive increase in the yield of cane, with higher doses; and (2) Application of groundnut cake in combination with the artificials (AmSO_4) is more beneficial than when applied alone at constant level of N.
	Sugar-cane (6 years).	(1) G.N. cake—50 lbs. N. (2) G.N. cake—40 lbs. N. plus AmSO_4 10 lbs. N. (3) G.N. cake—100 lbs. N. (4) G.N. cake—80 lbs. N. plus AmSO_4 20 lbs. N.		

Note.—At Aduthurai, a complex manual experiment designed by the Statistician, I.C.A.R., involving three dosages of N applied as cake and ammonium sulphate with and without green manure, and in presence and absence of three levels of P_2O_5 was conducted recently (1942-46). The findings of the results (yield data not available in the printed station reports), as analysed by the Statistician, I.C.A.R., and reported, indicate that green manure in combination with other forms of nitrogenous fertilizers such as ammonium sulphate responds better than in the absence of the latter. Among the various forms and proportions of N tried the application of groundnut cake and ammonium sulphate in the ratio of 1 : 1 with green leaf is stated to be very promising. All these show that the combination of inorganic and organic N is preferable to individual applications of either.

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AN ESSENTIALLY STATISTICAL APPROACH TO THE THERMODYNAMIC PROBLEM

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I. INTRODUCTION.

Though it is generally admitted that the methods of mechanics are not suitable for solving thermodynamic problems, yet the mechanical bias predominates in all the existing methods of statistical thermodynamics. In statistical thermodynamics, the problems, as usually formulated are essentially of mechanical nature and the probabilistic or statistical arguments are generally introduced as substitutes of mechanical methods, if and only when they fail. Now, in microscopic approaches to the thermodynamic problems, the thermodynamic systems are usually assumed to be composed of large numbers of constituent parts, of which the nature is not really known but is only postulated conveniently as mechanical. So an essentially statistical method, free from mechanical hypotheses about the nature of constituent parts, for the interpretations of thermodynamic problems may be considered desirable and overdue. Even, discussions of the classical phenomenological thermodynamics, according to which in a thermodynamic (equilibrium) state any physical quantity signifying some behaviour of the system can have only one value, when modified in light of the notions of fluctuations in the values of physical quantities based on the experiments on light-scattering, on the torsional oscillations of mirror suspended in high vacuum, etc., necessitates a purely statistical approach to these problems. In this paper, an attempt has been made to pursue an essentially statistical method for treatment of such problems.

With this end in view, a mathematical probability of occurrence of the system under consideration, in any state (which will be defined in the next section), has been suitably introduced in this paper as the starting point of the discussion. As defined, the expression for the probability contains two distribution-parameters, which, by introduction of suitable assumption analogous to the principle of maximum likelihood, are determined and are correlated with the 'real' state (observed in the sense of classical phenomenological thermodynamics¹). Up to this, all discussions have been made for the system kept in a definite environment. In the later portion of this paper, the environment of the system under consideration is slightly varied and the effects of the variations on the average behaviour of the system are calculated by introduction of the equation of continuity in a suitable form. Some important functions, characterising the behaviour of the equation of continuity, are identified as the entropy, the temperature and the chemical potential of the system. Other important results, viz., the non-decreasing property of entropy, statistics for microscopic distribution and the formulae for fluctuations, have been subsequently investigated.

¹ In future, 'in the sense of classical phenomenological thermodynamics' will be shortly referred to as 'in the classical sense'.

II. FORMULATION OF THE PROBLEM.

In this paper, the system means some finite quantities, M and E , of two types of entities, viz., matter and energy, enclosed in a definite volume in a definite environment.¹ In the discussion, if not specifically mentioned, the system is to be taken as open, i.e., there is no hindrance on free transfer of matter and energy between the system and the environment. The state of the system in a definite environment is taken as specified when a set of values (M , E) is ascribed to the quantities of matter and energy contained in the system. In contrast to the term 'real', used in the previous section, all these states will be referred to as 'virtual' states. In this connection it should be noted that the 'virtual' states are not purely hypothetical and not devoid of physical significance. They are realisable and are significant in experiments connected with fluctuation-phenomena; or better, they (the virtual states) are the fluctuating states about the real (thermodynamic) state.

The basic statistical investigation of this paper really consists of two simpler problems. The first is how to determine the law of distribution of occurrences of the system in a definite environment amongst states, from the knowledge of observed values of M and E in real states by introducing plausible assumptions. The other is how to investigate the consequences of changes in the environment of the system. From these all the usual informations of microscopic distribution are also obtained by introducing suitable assumptions about the constituent parts.

For simplicity, at present, the system will be assumed to be composed of chemically single type of material, and M and E are assumed to have discrete values. This is also quite in agreement with other modern methods according to which the system, being essentially a quantum system and being composed of molecules or the like, generally assumes discrete set of values of M and E .

III. THE LAW OF PROBABILITY-DISTRIBUTION.

Due to perfect randomness in values of M and E in virtual states of systems, corresponding to the same and the different environments, the matter and the energy contained in the system will be taken as unrelated entities. So it will be assumed that in a definite environment there is a constant *a priori* probability t for each unit quantity of matter to occur in the system considered, and that there is a constant *a priori* probability z for each unit of energy, such that for a quantity of matter of mass m it will be t^m , and for quantity of energy e it will be z^e .

Thus, if $W(E, M)$ be the weight of the states, i.e., the number of ways in which (E , M) can be realised together in the system, then the probability of occurrences of the system in the state specified by (M , E) is

$$P(t, z; E, M) = \frac{W(E, M) \cdot t^M \cdot z^E}{\sum_{E=0}^{\infty} \sum_{M=0}^{\infty} W(E, M) \cdot t^M \cdot z^E} = \frac{W(E, M) \cdot t^M \cdot z^E}{f(t, z)}, \quad \dots \quad (1)$$

where

$$f(t, z) = \sum_{E=0}^{\infty} \sum_{M=0}^{\infty} W(E, M) \cdot t^M \cdot z^E. \quad \dots \quad (2)$$

The function $f(t, z)$ is the usual characteristic function.

¹ In future, 'enclosed in a definite volume in a definite environment' will be simply referred to as 'in the definite environment'.

In the present discussion, for specification of distribution-law, $P(t, z; E, M)$ will be considered as functions of t, z and E, M will be considered as parameters, and so this will be briefly written as $P(t, z)$.

The expression (1) can also be written from a slightly different consideration. Now, if an equal *a priori* probability p be associated with all possible environments, and if one of the environments has the productive probabilities t and z respectively for unit quantity of matter and energy to occur in the system, and if $W(E, M)$ is used with the same significance as in the above, then the probability of occurrence of M and E is also given by (1).

In the expression (1) for $P(t, z)$ the possibility of infinite variation of M and E has been admitted. This will remind one of the infinite heat-bath (of course, here, infinite heat- and matter-bath) in the usual discussions of canonical assembly. But, even when the upper limit of variations of M, E be restricted to some large number \mathcal{M} and \mathcal{E} (as the case should always be in consequence of relativistic concept of finite universe), the expression for probability can also be put in the form (1). Let t'^M and z'^E be as before *a priori* probabilities of M and E to occur in the system and then as the universe is finite, so $(1-t')^{\mathcal{M}-M}$ and $(1-z')^{\mathcal{E}-E}$ should be taken as *a priori* probability of $\mathcal{M}-M$ and $\mathcal{E}-E$ occurring outside the system. Thus, with usual significance for $W(E, M)$, the probability can be written as

$$\begin{aligned}
 P(t', z'; E, M) &= \frac{W(E, M) \cdot t'^M \cdot z'^E \cdot (1-t')^{\mathcal{M}-M} \cdot (1-z')^{\mathcal{E}-E}}{\sum_{M=0}^{\mathcal{M}} \sum_{E=0}^{\mathcal{E}} W(E, M) \cdot t'^M \cdot z'^E \cdot (1-t')^{\mathcal{M}-M} \cdot (1-z')^{\mathcal{E}-E}} \\
 &= \frac{W(E, M) \cdot \left(\frac{t'}{1-t'}\right)^M \cdot \left(\frac{z'}{1-z'}\right)^E}{\sum_{E=0}^{\mathcal{E}} \sum_{M=0}^{\mathcal{M}} W(E, M) \cdot \left(\frac{t'}{1-t'}\right)^M \cdot \left(\frac{z'}{1-z'}\right)^E} \\
 &= \frac{W(E, M) \cdot t^M \cdot z^E}{\sum_{E=0}^{\mathcal{E}} \sum_{M=0}^{\mathcal{M}} W(E, M) \cdot t^M \cdot z^E} \\
 &= P(t, z),
 \end{aligned}$$

where $t = \frac{t'}{1-t'}$ and $z = \frac{z'}{1-z'}$.

This is of the same form as (1), only interpretations and ranges of t and z are different. The summation can also be extended to infinity as due to finiteness of total energy and matter in the universe,

$$W(E, M) = 0, \text{ when } M > \mathcal{M} \text{ or } E > \mathcal{E}.$$

For determination of the distribution-parameters t and z , in agreement with usual idea of statistical equilibrium, it will be assumed that the 'real' values M_0 and E_0 (taken to be known from observations in the classical sense) correspond to the maximum of probability of occurrence, considered as function of t and z . This assumption is quite similar to the principle of maximum likelihood. Again the present idea of associating a probability-distribution of (M, E) , besides a set of (M_0, E_0) , to each 'real' state is also similar to that of Szilard (1925).

IV. BEHAVIOUR OF THE FUNCTIONS $W(E, M)$, $f(t, z)$, $P(t, z)$.

It is now necessary to discuss the nature of $W(E, M)$ and of the series in the denominator of the relation (1) denoted by $f(t, z)$. This discussion will help to form ideas about the nature of the probability function $P(t, z)$, and to show that the function $P(t, z)$ has really a unique maximum.

For the clear understanding of the above, in the beginning, some well-known special cases are discussed, and then, as a way of generalisation necessary postulates about the nature of the above functions have been introduced for general cases. With this end in view, the case of the system in gaseous phase (where contributions of the radiation-energy and the mutual-interaction-energy are not significant) has been discussed in details. Let us denote $\frac{M}{m}$ by N , where m is the mass of each constituent part of the system. In this case, $W(E, M)$ is partition of the number E into N parts according to certain rule of partition and so is essentially a positive integer, and as a way of definition, $W(0, 0)$ is to be taken as one. Obviously $W(E, M)$, being partitions of a number E into N parts, depends on the instantaneous numerical values of E and N and is to be taken as independent of all external parameters. In the general case, as a way of generalisation, it will be taken that $W(E, M)$ is essentially a positive integer and is independent of external parameters.

To have the clear insight about the behaviour of $f(t, z)$ as in the above, simple cases will be discussed first. In the simplest case, the energy-levels for constituent parts may be taken as equidistant and non-degenerate, i.e. $E_i = i\Delta$, such that energy-quanta are simple integral multiple of same quantum of energy. Here, if Δ is taken to be unit of measurement for energy, then the set of values of E will be set of integers. In these cases, discussions proceed very simply as follows.

Case A:

The system is such that any number of constituent parts may have the same energy. This corresponds to the case of ensembles of Bose-Einstein particles. Here $W(E, M)$ is the partition of energy E into N parts with no restriction.

Then,

$$W(E, M) = P(E/N/*), \quad \dots \quad \dagger \quad \dots \quad \dots \quad (3)$$

and

$$f(t, z) = \prod_{n=0}^{\infty} (1 - t^n \cdot z^n)^{-1}. \quad \dots \quad \dots \quad \dots \quad (4)$$

Case B:

The system is such that no two constituent particles can have simultaneously equal energies. This case corresponds to the case of ensemble of Fermi-Dirac particles. Here $W(E, M)$ is partition of E into N parts where no two parts can be equal. Then,

$$W(E, M) = P_{(\nless 1)}(E/N/*), \quad \dots \quad \dots \quad \dots \quad (5)$$

and

$$f(t, z) = \prod_{n=0}^{\infty} (1 + t^n z^n). \quad \dots \quad \dots \quad \dots \quad (6)$$

[†] Notations, used here for partition of numbers, are similar to those in *Algebra* (Part II), G. Chrystal. (1922, A. and C. Black Ltd., London.)

Case C:

The system under consideration is such that the number of constituent parts, having simultaneously equal energies, cannot exceed a certain fixed number d . This corresponds to Gentile's statistics. In this, $W(E, M)$ is the partition of E into N parts in which up to d repetitions are possible. Then,

$$W(E, M) = P_{(\nearrow d)}(E/N/\star), \quad \dots \quad (7)$$

and

$$f(t, z) = \prod_{n=0}^{\infty} \left\{ \frac{1 - t^{m(d+1)} \cdot z^{n(d+1)}}{1 - t^m \cdot z^n} \right\}. \quad \dots \quad (8)$$

Case D:

In the case, when the constituent parts are localised and distinguishable, these become

$$W(E, M) = \frac{(E+N-1)!}{N! (N-1)! E!}, \quad \dots \quad (9)$$

and

$$\begin{aligned} f(t, z) &= \sum_{N=0}^{\infty} \sum_{E=0}^{\infty} \frac{1}{N!} \cdot \frac{(E+N-1)!}{(N-1)! E!} \cdot t^{mN} \cdot z^E \\ &= \sum_{N=0}^{\infty} \frac{1}{N!} \cdot t^{mN} \cdot (1-z)^{-N} = e^{\frac{t^m}{1-z}} \\ &= e^{t^m \cdot \sum_0^{\infty} z^n} \\ &= \prod_{n=0}^{\infty} e^{t^m \cdot z^n}. \end{aligned}$$

The above discussion can be very easily extended to the case where there is a degeneracy of eigen-states in energy levels, i.e. where every energy-level is not of equal weight as in the case of degeneracy. If A_n be the weight of n th energy-level (i.e. the degree of degeneracy of states), then the above formulae can be written as follows:

Case A:

$$f(t, z) = \prod_{n=0}^{\infty} (1 - t^m \cdot z^n)^{-A_n}. \quad \dots \quad (4')$$

Case B:

$$f(t, z) = \prod_{n=0}^{\infty} (1 + t^m \cdot z^n)^{A_n}. \quad \dots \quad (6')$$

Case C:

$$f(t, z) = \prod_{n=0}^{\infty} \left\{ \frac{1 - t^{m(d+1)} \cdot z^{n(d+1)}}{1 - t^m \cdot z^n} \right\}^{A_n}. \quad \dots \quad (8')$$

Case D:

$$f(t, z) = \prod_{n=0}^{\infty} e^{A_n \cdot t^m \cdot z^n} \quad \dots \quad (10')$$

The present discussion can also be very simply extended to the cases where the energy-levels are not equally spaced and the corresponding expression can be obtained as follows:

Case A:

$$f(t, z) = \prod_{n=0}^{\infty} (1 - t^m \cdot z^{\epsilon_n})^{-1}, \quad \dots \dots \dots (11)$$

and in the case of degeneracy,

$$f(t, z) = \prod_{n=0}^{\infty} (1 - t^m \cdot z^{\epsilon_n})^{-A_n}, \quad \dots \dots \dots (12)$$

Case B:

$$f(t, z) = \prod_{n=0}^{\infty} (1 + t^m \cdot z^{\epsilon_n}), \quad \dots \dots \dots (13)$$

and in the case of degeneracy,

$$f(t, z) = \prod_{n=0}^{\infty} (1 + t^m \cdot z^{\epsilon_n})^{A_n}, \quad \dots \dots \dots (14)$$

Case C:

$$f(t, z) = \prod_{n=0}^{\infty} \left\{ \frac{1 - t^{m(d+1)} \cdot z^{(d+1)\epsilon_n}}{1 - t^m \cdot z^{\epsilon_n}} \right\} \dots \dots (15)$$

and in the case of degeneracy,

$$f(t, z) = \prod_{n=0}^{\infty} \left\{ \frac{1 - t^{m(d+1)} \cdot z^{(d+1)\epsilon_n}}{1 - t^m \cdot z^{\epsilon_n}} \right\}^{A_n}, \quad \dots \dots (16)$$

where ϵ_n is the energy of the n th energy-state of the constituent parts, and A_n is the degree of degeneracy of n th energy-state.

Now, as in the cases discussed here, $f(t, z)$ has been found to be expressible in form of infinite product, and as t and z lie between 0 and 1, so the continuity, the differentiability, etc. of $f(t, z)$ follow simply from the well-known properties of infinite product. When ϵ_n 's are commensurable, such that ultimately they are expressible as integers with a suitable choice of the unit of energy, then $f(t, z)$ also reduces to the form referred above. For other case, i.e. when ϵ_n 's are not commensurable, careful analysis is required and is postponed at present for future. Here, in general, $f(t, z)$ and so $P(t, z)$ will be postulated as a function of t and z having continuous derivatives of first two orders within the domain of t and z .

Theorem: If $f(z)$ be the characteristic function of the system and if it is possible to distinguish in it two groups which together make up the whole system and have characteristic function $f_1(z)$ and $f_2(z)$ respectively, then the characteristic function of the entire system is factorisable as $f(z) = f_1(z) \cdot f_2(z)$.

Let M_1, M_2 be the number of particles in two groups, where $M_1 + M_2 = M$ and let E_1 and E_2 be corresponding energies, where $E_1 + E_2 = E$ at any instant. Then,

$$W(E, M) = \sum_{\substack{E = E_1 + E_2 \\ M = M_1 + M_2}} W_1(E_1, M_1) \cdot W_2(E_2, M_2) \quad \dots \dots \dots (17)$$

$$\therefore f(t, z) = \sum_{M=0}^{\infty} \sum_{E=0}^{\infty} W(E, M) \cdot t^M \cdot z^E$$

$$\begin{aligned}
\therefore f(t, z) &= \sum_{M=0}^{\infty} \sum_{E=0}^{\infty} \sum_{\substack{E=E_1+E_2 \\ M=M_1+M_2}} W_1(E_1, M_1) \cdot W_2(E_2, M_2) \cdot t^{M_1+M_2} \cdot z^{E_1+E_2} \\
&= \left\{ \sum_{M_1=0}^{\infty} \sum_{E_1=0}^{\infty} W_1(E_1, M_1) \cdot t^{M_1} \cdot z^{E_1} \right\} \\
&\quad \times \left\{ \sum_{M_2=0}^{\infty} \sum_{E_2=0}^{\infty} W_2(E_2, M_2) \cdot t^{M_2} \cdot z^{E_2} \right\} \\
&= f_1(t, z) \cdot f_2(t, z) \cdot \dots \dots \dots \dots \dots \dots \dots \dots (18)
\end{aligned}$$

Similarly, it can be shown that if the system may be looked upon as consisting of n number of sub-systems, then $f(t, z)$ is factorisable into n components.

Now, from the equation (1) it is obvious that $P(t, z) = 0$ when either $t = 0$, or $z = 0$, or both. As some sort of interpretation, it is to be remembered that $t = 0$ signifies that the occurrence of any particle in the volume is highly improbable, i.e. there is an infinite rarefaction of matter in the volume, and so the probability of occurrence of non-zero value of M is very small, i.e. zero. Similarly $z = 0$ corresponds to infinite rarefaction of energy, and so $P(t, z)$ for finite non-zero value of E is obviously zero. Again $t = 1$ and $z = 1$ can be similarly interpreted as the case of infinite accumulation of matter and energy respectively in the volume, so $P(t, z) = 0$, when $t = 1$, or $z = 1$, or both, for finite values of E and M , as this is incompatible with the idea of infinite accumulation. Contrary to the cases $z = 0$ or $t = 0$, for $z = 1$ or $t = 1$, the form (1) does not give $P(t, z) = 0$. This has been introduced here as a sort of characteristic of the nature of the function $P(t, z)$ to fulfil the physical requirements.

Moreover, as defined, the continuous and differentiable function $P(t, z)$ is positive for all values of t, z , so $P(t, z)$ must have at least one maximum within the domains of t and z .

V. SPECIFICATION OF VALUES OF t, z CORRESPONDING TO THE OBSERVED STATE.

Now, the probability of occurrence of E and M in any state, as given by (1), is

$$P(t, z) = \frac{W(E, M) \cdot t^M \cdot z^E}{f(t, z)}.$$

Then, the probability of occurrence of an observed state with the observed value of E_0 and M_0 is

$$P(t_0, z_0) = \frac{W(E_0, M_0) \cdot t_0^{M_0} \cdot z_0^{E_0}}{f(t_0, z_0)},$$

where t_0, z_0 are such that for these values of t, z , $P(t, z)$ has a maximum with observed values of M and E . Then, t_0 and z_0 are given by the equations,

$$M_0 = t_0 \cdot \frac{\partial}{\partial t_0} \{ \log f(t_0, z_0) \} \quad \dots \dots \dots (19)$$

$$\text{and} \quad E_0 = z_0 \cdot \frac{\partial}{\partial z_0} \{ \log f(t_0, z_0) \}. \quad \dots \dots \dots (20)$$

It is important to note the relation between M and E as specified in (19) and (20) with average values \bar{M} and \bar{E} obtained when $t = t_0$ and $z = z_0$. One thus obtains,

$$\bar{M} = \frac{\sum \sum M \cdot W(E, M) \cdot t_0^M \cdot z_0^E}{\sum \sum W(E, M) \cdot t_0^M \cdot z_0^E} = t_0 \cdot \frac{\partial}{\partial t_0} \{ \log f(t_0, z_0) \},$$

and

$$\bar{E} = \frac{\sum \sum E \cdot W(E, M) \cdot t_0^M \cdot z_0^E}{\sum \sum W(E, M) \cdot t_0^M \cdot z_0^E} = z_0 \cdot \frac{\partial}{\partial z_0} \{ \log f(t_0, z_0) \}.$$

So average values \bar{M} and \bar{E} are identical with those M_0, E_0 defined by (19) and (20) and so hereafter M, E will be replaced by M_0, E_0 freely.

VI. UNIQUENESS OF t_0 AND z_0 .

Now, to justify the correlation of t_0, z_0 with physical properties of the system under consideration, it will be necessary to show that (t_0, z_0) , as defined by (19) and (20), is unique. For this, $P(t, z)$ will be shown to have a unique maximum, which will be done by showing that every stationary value of $P(t, z)$, in the range of t, z mentioned above, must be a maximum of $P(t, z)$, and so $P(t, z)$ being a single-valued function with continuous derivatives of first two orders cannot have more than one maximum of $P(t, z)$. To decide the nature of stationary values of $P(t, z)$, the function

$$\Phi(t, z) = \log P(t, z) \quad \dots \quad (21)$$

will be considered.

On expanding the function $\Phi(t, z)$ about the values t_0, z_0 by Taylor's theorem of two variables, one can write,

$$\begin{aligned} \Phi(t, z) = & \Phi(t_0, z_0) + \{ \Phi_{t_0 t_0} (t - t_0)^2 + 2 \cdot \Phi_{t_0 z_0} (t - t_0)(z - z_0) + \Phi_{z_0 z_0} (z - z_0)^2 \} \\ & + \{ \Phi_{t_0 t_0 t_0} (t - t_0)^3 + 3 \cdot \Phi_{t_0 t_0 z_0} (t - t_0)^2 (z - z_0) + 3 \cdot \Phi_{t_0 z_0 z_0} (t - t_0)(z - z_0)^2 \\ & + \Phi_{z_0 z_0 z_0} (z - z_0)^3 \} + \dots \quad \dots \quad (22) \end{aligned}$$

where t_0, z_0 are defined by (19).

Now, by straightforward calculations it can be shown that

$$\begin{aligned} [\Phi_{tt}]_{t_0, z_0} = & -\frac{1}{t_0^2} \cdot \frac{1}{\{f(t_0, z_0)\}^2} \\ & \times \left[\sum \sum \sum \sum (M - M')^2 \cdot W(E, M) \cdot W(E', M') \cdot t_0^{M+M'} \cdot z_0^{E+E'} \right] < 0, \\ [\Phi_{zz}]_{t_0, z_0} = & -\frac{1}{z_0^2} \cdot \frac{1}{\{f(t_0, z_0)\}^2} \\ & \times \left[\sum \sum \sum \sum (E - E')^2 \cdot W(E, M) \cdot W(E', M') \cdot t_0^{M+M'} \cdot z_0^{E+E'} \right] < 0, \end{aligned}$$

and

$$\begin{aligned}
 \left| \frac{\Phi_{t_0 t_0} \Phi_{t_0 z_0}}{\Phi_{t_0} \Phi_{z_0}} \right| &= \frac{1}{t_0 \cdot z_0} \cdot \frac{1}{\{f(t_0, z_0)\}^2} \cdot \sum \sum \sum \sum \left| \frac{M-M'}{E-E'} \quad \frac{M''-M'''}{E''-E'''} \right|^2 \\
 &\quad \times W(E, M) \cdot W(E', M') \cdot W(E'', M'') \cdot W(E''', M''') \\
 &\quad \times t_0^{M+M'+M''+M'''} \\
 &\quad \times z_0^{E+E'+E''+E'''} \\
 &> 0.
 \end{aligned}$$

So the expression within the bracket in the second term in (22) is negative definite. So $\Phi(t, z)$ has maximum at (t_0, z_0) if (t_0, z_0) corresponds to a stationary value of the function. Thus, $\Phi(t, z)$ and so $P(t, z)$ have only one maximum. Thus (t_0, z_0) is the unique set.

VII. INFLUENCE OF VARIATIONS IN THE ENVIRONMENT.

The behaviour of the system in a definite environment has been investigated above. The statement that the system is in a definite environment implies the existence of some external parameters—other than the quantities already introduced—which are kept constant and so are not explicitly mentioned in previous discussions. It is easy to see that the volume of the system is one of the parameters; and the others may be the area of the boundary-walls when surface tension is significant, the intensity of current when the system is a portion of conducting medium, some parameters involved in the definition of the external field of forces if any, etc. These parameters will be denoted by x_i 's. Properties of the system in different virtual states, and the average properties will evidently depend on the values of these x_i 's. The effect of the variations in x_i 's on the average properties will be considered now. This consideration will be necessary to make the theory complete from the point of view of applications, as the influence of variations in environments on the behaviour of the system is of great importance for application to physics and other sciences.

With this object in view, we shall first consider such infinitesimal variation in the parameters x_i 's that due to this variation there is no change in M , the quantity of matter contained in the system. For actual physical system, the process of variations of the above type can be visualised if it is imagined that during the process of such variations the envelope of the system is replaced by a conducting one, which is introduced just before commencement of the process and is removed just after the process.¹ Then, if (M, E) be the mass and the energy in the virtual state of the system at commencement of the variation, then the equation of continuity for energy can be written as

$$dE = \sum \frac{\partial E}{\partial x_i} \cdot dx_i + d'q, \quad \dots \quad (23)$$

where $\frac{\partial E}{\partial x_i}$'s are values in the virtual state of the system² and $d'q$ is the increase of the energy in the system which is not accounted for by the first term, viz. the increase due to flow of energy from outside in the system and other similar processes.

¹ Here, as in classical phenomenological thermodynamics, it is assumed that the system is not materially affected by introduction or removal of the walls.

² Here, it is implicitly assumed that there is a value of $\partial E / \partial x_i$ for every virtual state specified by E, M . This will be more plausible if each virtual state of the system is looked upon as state of virtual system (replica).

Now, as which virtual state is the initial virtual state of the system cannot be determined, and as only average properties (which are here the same as those corresponding to the real state) of system are of real physical significance, so the equation (when there is no generation or annihilation of energy) should be written as

$$d\bar{E} = \sum_i \frac{\partial \bar{E}}{\partial x_i} \cdot dx_i + d'Q, \quad \dots \quad \dots \quad \dots \quad (24)$$

where $d'Q$ is the *average* value of all $d'q$'s. This equation of continuity may be looked upon as a form of the first law of thermodynamics. Now

$$d'Q = d\bar{E} - \sum_i \frac{\partial \bar{E}}{\partial x_i} \cdot dx_i, \quad \dots \quad \dots \quad \dots \quad (25)$$

where

$$\begin{aligned} \left(- \frac{\partial \bar{E}}{\partial x_i} \right) &= \frac{\sum_{E=0}^{\infty} \sum_{M=0}^{\infty} \left(- \frac{\partial E}{\partial x_i} \right) \cdot W(E, M) \cdot t_0^M \cdot z_0^E}{\sum_{E=0}^{\infty} \sum_{M=0}^{\infty} W(E, M) \cdot t_0^M \cdot z_0^E} \\ &= \frac{1}{\log \frac{1}{z_0}} \cdot \frac{\partial}{\partial x_i} \{ \log f(t_0, z_0) \} \quad \dots \quad \dots \quad \dots \quad (26) \end{aligned}$$

as $W(E, M)$ is independent of the external parameter.

Now, if the system after variation of environment be again allowed to the new state for sufficiently long time for establishment of the statistical equilibrium, then the 'real' state of the system in the definite environment (the altered environment) will be specified by two distribution-parameters, in general, different from t_0 and z_0 ; let them be $t_0 + dt_0$ and $z_0 + dz_0$. Thus, the variation, considered above, is a very slow process from one equilibrium state to another and can easily be recognised as the usual reversible variations of thermodynamics. For this variation, when both sides of the equation (24) are multiplied by $\left(\log \frac{1}{z_0} \right)$, the relation becomes

$$\begin{aligned} \left(\log \frac{1}{z_0} \right) \cdot d'Q &= \left(\log \frac{1}{z_0} \right) \cdot \left\{ d\bar{E} - \sum_i \frac{\partial \bar{E}}{\partial x_i} \cdot dx_i \right\} \\ &= \left(\log \frac{1}{z_0} \right) \cdot d\bar{E} + \sum_i \frac{\partial}{\partial x_i} \{ \log f(t_0, z_0) \} \cdot dx_i \\ &= d \left\{ \left(\log \frac{1}{z_0} \right) \cdot \bar{E} \right\} + \sum_i \frac{\partial}{\partial x_i} \cdot \{ \log f(t_0, z_0) \} dx_i \\ &\quad + \frac{\partial}{\partial z_0} \{ \log f(t_0, z_0) \} dz_0 \\ &= d \left\{ \left(\log \frac{1}{z_0} \right) \cdot \bar{E} + \log f(t_0, z_0) \right\} - \frac{\partial}{\partial t_0} \{ \log f(t_0, z_0) \} \cdot dt_0 \\ &= d \left\{ \left(\log \frac{1}{z_0} \right) \cdot E + \log f(t_0, z_0) - N \cdot \log t_0 \right\} \quad \dots \quad \dots \quad (27) \end{aligned}$$

This shows that $\left(\log \frac{1}{z_0}\right)$ is the integrating factor of $d'Q$, and the integral can only be determined for finite reversible variations composed of infinitesimal variations.

The integrating factor $\left(\log \frac{1}{z_0}\right)$ of the equation is to be taken to be proportional to $\frac{1}{kT}$ and, after choice of scale, one can write,

$$z_0 = e^{-\frac{1}{kT}}, \quad \dots \dots \dots (28)$$

and S , the corresponding integral, is, as usual, to be interpreted as the entropy of the system and is given by

$$\frac{dS}{k} = \frac{d'Q}{kT} = d \left[\frac{E}{kT} + \log F(t_0, T) - N \cdot \log t_0 \right], \quad \dots \dots (29)$$

where

$$F(t_0, T) = f(t_0, z_0). \quad \dots \dots \dots (30)$$

Then,

$$S = \frac{E}{T} + k \cdot \log F(t_0, T) - N \cdot k \cdot \log t_0 + S_0. \quad \dots \dots (31)$$

If the concept of absolute entropy is introduced after Planck, then,

$$S_0 = 0, \quad \dots \dots \dots (32)$$

and

$$S = \frac{E}{T} + k \cdot \log F(t_0, T) - Nk \cdot \log t_0 \quad \dots \dots \dots (33)$$

Then,

$$\Psi = k \cdot \log F(t_0, T) - Nk \cdot \log t_0. \quad \dots \dots \dots (34)$$

$d'Q = T \cdot dS$ can now be easily interpreted as heat supplied to the system.

$d\bar{E}$ is the change of total energy. Then, $-\sum \frac{\partial \bar{E}}{\partial x_i} \cdot dx_i$ can be interpreted as the external work done by the system. Thus, if the generalised forces on the system be taken as X_i , then one obtains

$$X_i = \frac{\partial \bar{E}}{\partial x_i} \cdot \dots \dots \dots (35)$$

Thus, if the system under consideration be taken as of the mechanical (classical or quantum) nature, then the equation can be recognised as the usual equation of the principle of adiabatic invariance, which principle has been discussed for systems of classical and quantum mechanics by Boltzmann (1866), Clausius (Routh, 1905), Einstein (Sommerfeld, 1923), Born (1927) and others from completely different considerations.

VIII. INTRODUCTION OF CONCEPT OF CHEMICAL POTENTIAL.

Now, as in the above section, the equation of continuity of matter (after proper averaging) can be written as

$$d\bar{M} = \sum \frac{\partial \bar{M}}{\partial x_i} \cdot dx_i + d'm, \quad \dots \dots \dots (36)$$

where $d'm$ is the quantity of matter flowing into the volume. (E is kept constant in variation, as some variables are to be kept constant such that this can be recognised as the previous system.)

Now, as before, one obtains

$$\begin{aligned}
 -\frac{\partial \bar{M}}{\partial x_i} &= \frac{\sum_{E=0}^{\infty} \sum_{M=0}^{\infty} \left(-\frac{\partial M}{\partial x_i} \right) \cdot W(E, M) \cdot t_0^M \cdot z_0^E}{\sum_{E=0}^{\infty} \sum_{M=0}^{\infty} W(E, M) \cdot t_0^M \cdot z_0^E} \\
 &= \frac{1}{\log \frac{1}{t_0}} \cdot \frac{\partial}{\partial x_i} \{ \log f(t_0, z_0) \}. \quad \dots \quad (36A)
 \end{aligned}$$

Then,

$$\begin{aligned}
 \left(\log \frac{1}{t_0} \right) \cdot d'm &= \left(\log \frac{1}{t_0} \right) \cdot \left[d\bar{M} - \sum \frac{\partial \bar{M}}{\partial x_i} \cdot dx_i \right] \\
 &= d \left\{ \left(\log \frac{1}{t_0} \right) \cdot \bar{M} \right\} + \sum \frac{\partial}{\partial x_i} \left\{ \log f(t_0, z_0) \right\} dx_i + \frac{\partial}{\partial t_0} \left\{ \log f(t_0, z_0) \right\} dz_0 \\
 &= d \left\{ \left(\log \frac{1}{t_0} \right) \cdot \bar{M} + \log f(t_0, z_0) \right\} - \frac{\partial}{\partial z_0} \left\{ \log f(t_0, z_0) \right\} dz_0 \\
 &= d \left\{ \left(\log \frac{1}{t_0} \right) \cdot \bar{M} + \log f(t_0, z_0) - E \cdot \log z_0 \right\} \\
 &= \frac{1}{k} \cdot dS. \quad \dots \quad (37)
 \end{aligned}$$

Now, $d'm$ is the increase of M not due to any change of parameter and so due to flow, then,

$$\log t_0 = -\frac{1}{k} \left(\frac{\partial S}{\partial \bar{M}} \right)_{E, x_i} = -\frac{1}{k} \left(\frac{\partial S}{\partial \bar{M}} \right)_{E, x_i} \quad \dots \quad (38)$$

$$= \frac{\mu'}{mkT} = \frac{\mu}{kT}, \quad \dots \quad (39)$$

where μ is usual chemical potential, m being mass of the constituent particle.

From the above discussions, it follows that the equations of continuity of energy and matter lead to the same integral, i.e., the entropy. Thus, so far as definition of entropy is concerned, the energy and the matter have the same rôle. From the present general discussion of the thermodynamic problem it is clear that the special stress on the significance of energy in usual discussions of thermodynamics is not necessary in mathematical developments. Also, it is to be noted that in the present discussion no specific assumption about the properties of energy and matter, other than the laws of conservations and the possibility of variation with external parameters, has been used.

Now, in the present discussion, t_0 and z_0 have been introduced as *a priori* probabilities that unit quantities of mass and energy occur in the specified volume. From the macroscopic point of view, it is known that the flow of energy is controlled by temperature, and the transfer of mass by chemical potential, so relations between t_0 and μ , z_0 and T , as obtained here, are quite satisfactory.

IX. INCREASING PROPERTY OF ENTROPY.

From section VII we have,

$$S = -\log \frac{t_0^M \cdot z_0^E}{f(t_0, z_0)} \quad \dots \quad (40)$$

It has been proved in sections V and VI that the argument of the logarithm in the equation (40) has one unique maximum for values t_0 and z_0 of t and z . So the function $S(t, z)$ has a unique minimum for values of t_0 and z_0 .

Let us consider two isolated systems of some constituent parts, and let (t'_0, z'_0) and (t''_0, z''_0) determine their states respectively. Let E' and E'' be their total energies, and M' , M'' be number of constituent parts respectively. Then their entropies, $S'(t'_0, z'_0)$ and $S''(t''_0, z''_0)$, are given by

$$S'(t'_0, z'_0) = -\log \frac{t_0^{M'} \cdot z_0^{E'}}{f'(t'_0, z'_0)}, \quad \dots \quad (41)$$

$$S''(t''_0, z''_0) = -\log \frac{t_0^{M''} \cdot z_0^{E''}}{f''(t''_0, z''_0)}, \quad \dots \quad (42)$$

where the functions S' , S'' have unique minimum, i.e., for (t'_0, z'_0) and (t''_0, z''_0) respectively, i.e.,

$$S'(t, z) \geq S'(t'_0, z'_0), \quad \dots \quad (43)$$

and

$$S''(t, z) \geq S''(t''_0, z''_0), \quad \dots \quad (44)$$

where (t, z) be any other set of values.

If the systems be coupled in any manner provided that both the systems, taken together, remain isolated, i.e. there is no loss of energy and matter in the total system, then,

$$E = E' + E'', \quad \dots \quad (45)$$

$$M = M' + M'', \quad \dots \quad (46)$$

where E , M are energy and mass of the total system.

Let (t_0, z_0) define the state of the compound system after the statistical equilibrium has been set in. Then the entropy is given by

$$\begin{aligned} S(t_0, z_0) &= -\log \frac{t_0^M \cdot z_0^E}{f(t_0, z_0)} = -\log \left[\frac{t_0^{M'} \cdot z_0^{E'}}{f'(t_0, z_0)} \cdot \frac{t_0^{M''} \cdot z_0^{E''}}{f''(t_0, z_0)} \right] \\ &= -\log \frac{t_0^{M'} \cdot z_0^{E'}}{f'(t_0, z_0)} - \log \frac{t_0^{M''} \cdot z_0^{E''}}{f''(t_0, z_0)} \\ &= S'(t_0, z_0) + S''(t_0, z_0) \\ &\geq S'(t'_0, z'_0) + S''(t''_0, z''_0) \quad \dots \quad (47) \end{aligned}$$

[by (44) and (18)].

Thus the entropy of a closed system cannot decrease.

X. LAWS OF MICROSCOPIC DISTRIBUTIONS.

The previous discussions are mainly of microscopic nature and no assumption has been made about the nature of the constituent parts of the system. It will be now shown the usual laws for microscopic distributions can also be simply deduced in the present discussions, if the usual hypothesis about the microscopic nature of the system be made. So the system under consideration will be assumed to be composed of a large number of small constituent parts, viz. molecules, atoms, ions, etc. Let us write

$$w(E, N) = W(E, M). \quad \dots \quad (48)$$

Let the energy of one of the microscopic state of constituent parts be denoted by ϵ_r and let n_r be the number of constituent particles in the state at any instant. In statistical considerations, the expected value \bar{n}_r of n_r is of real interest and is to be calculated. Now, the number of ways in which a particular value n_r with energy ϵ_r is realised when the total energy of the system is E and the total number of constituent parts is N , is denoted by $w'(E - n_r \epsilon_r, N - n_r)$, then $w'(E - n_r \epsilon_r, N - n_r)$ denotes the number of ways in which $E - n_r \epsilon_r$ can be partitioned in $N - n_r$ parts, such that no one of the parts is equal to ϵ_r . Then, on writing $t_1 = t_0^m$, the expected value \bar{n}_r is given by

$$\begin{aligned} \bar{n}_r &= \frac{\sum_{E=0}^{\infty} \sum_{M=0}^{\infty} \sum_{n_r=0}^N n_r \cdot w'(E - n_r \epsilon_r, N - n_r) \cdot t_1^N \cdot z_0^E}{\sum_{E=0}^{\infty} \sum_{N=0}^{\infty} w(E, N) \cdot t_1^N \cdot z_0^E} \\ &= \frac{\left(\sum_{n_r=0}^{\infty} n_r \cdot t_1 \cdot z_0^{n_r \epsilon_r} \right) \left[1 + \sum_{N=0}^{\infty} \sum_{E=0}^{\infty} w'(E - n_r \epsilon_r, N - n_r) \cdot t_1^N \cdot z_0^E \right]}{\left(1 + \sum_{n_r=0}^{\infty} t_1^{n_r} \cdot z_0^{n_r \epsilon_r} \right) \left[1 + \sum_{N=0}^{\infty} \sum_{E=0}^{\infty} w'(E - n_r \epsilon_r, N - n_r) \cdot t_1^N \cdot z_0^E \right]} \\ &= \frac{t_1 \cdot \frac{\partial}{\partial t_1} \left(1 + \sum_{n_r=0}^{\infty} t_1^{n_r} \cdot z_0^{n_r \epsilon_r} \right)}{\left(1 + \sum_{n_r=0}^{\infty} t_1^{n_r} \cdot z_0^{n_r \epsilon_r} \right)} = t_1 \cdot \frac{\partial}{\partial t_1} \left\{ \log g_r(t_0, z_0) \right\}. \quad \dots \quad (49) \end{aligned}$$

Now,

$$1 + \sum_{n_r=0}^{\infty} t_0^{n_r} \cdot z_0^{n_r \epsilon_r}$$

is one of the generating functions as discussed in Section IV, and is denoted by $g_r(t_0, z_0)$.

$$\therefore \bar{n}_r = t_1 \cdot \frac{\partial}{\partial t_1} \left\{ \log g_r(t_0, z_0) \right\}. \quad \dots \quad (50)$$

Then, in the case of the system composed of Bose particles :

$$g_r(t_0, z_0) = \left\{ 1 + \sum_{n_r=1}^{\infty} t_0^m \cdot z_0^{n_r \epsilon_r} \right\} = \left\{ \frac{1}{1 - t_0^m z_0^{\epsilon_r}} \right\}^{A_r}$$

$$\therefore \bar{n}_r = \frac{A_r}{t_0^{-m} \cdot z_0^{-\epsilon_r} - 1} = \frac{A_r}{e^{\frac{m\mu + \epsilon_r}{kT}} - 1} \quad \dots \quad \dots \quad \dots \quad (51)$$

In the case of the system composed of Fermi-Dirac particles:

$$g_r = \left(1 + t_0^m z_0^{\epsilon_r} \right)^{A_r}$$

$$\therefore \bar{n}_r = \frac{A_r}{t_0^{-m} \cdot z_0^{-\epsilon_r} + 1} = \frac{A_r}{e^{\frac{m\mu + \epsilon_r}{kT}} + 1} \quad \dots \quad \dots \quad \dots \quad (52)$$

In the case of the system composed of Gentile's particles:

$$g_r = \left\{ \frac{1 - t_0^{m(d+1)} \cdot z_0^{\epsilon_r(d+1)}}{1 - t_0^m z_0^{\epsilon_r}} \right\}^{A_r}$$

$$\therefore \bar{n}_r = A_r \left\{ \frac{1}{t_0^{-m} \cdot z_0^{-\epsilon_r} - 1} - \frac{(d+1)}{t_0^{-m(d+1)} \cdot z_0^{-(d+1)\epsilon_r} - 1} \right\}$$

$$= A_r \left\{ \frac{1}{e^{\frac{m\mu + \epsilon_r}{kT}} - 1} - \frac{(d+1)}{e^{\frac{(d+1)(m\mu + \epsilon_r)}{kT}} - 1} \right\} \quad \dots \quad (53)$$

In the case of the classical system:

$$g_r = e^{A_r \cdot t_0^m \cdot z_0^{\epsilon_r}}$$

$$\therefore \bar{n}_r = A_r \cdot t_0^m \cdot z_0^{\epsilon_r} = A_r \cdot e^{\frac{m\mu + \epsilon_r}{kT}} \quad \dots \quad \dots \quad \dots \quad (54)$$

XI. FLUCTUATIONS.

As fluctuation of average properties is a most important concept of statistical thermodynamics, the usual results will be deduced here before concluding the discussion. Now,

$$\bar{E}^2 = \frac{\sum_{E=0}^{\infty} \sum_{M=0}^{\infty} E^2 \cdot W(E, M) \cdot t_0^M \cdot z_0^E}{\sum_{E=0}^{\infty} \sum_{M=0}^{\infty} W(E, M) \cdot t_0^M \cdot z_0^E} = \frac{1}{\{f(t_0, z_0)\}} \cdot \left\{ z_0 \frac{\partial}{\partial z_0} \right\}^2 \cdot \{f(t_0, z_0)\}$$

$$\bar{E}^2 = \frac{1}{f(t_0, z_0)} \cdot \left\{ z_0 \frac{\partial}{\partial z_0} \right\} \cdot \left\{ \bar{E} \cdot f(t_0, z_0) \right\} = \bar{E}^2 + z_0 \cdot \frac{\partial \bar{E}}{\partial z_0}$$

$$\therefore \overline{(E - \bar{E})^2} = \bar{E}^2 - \bar{E}^2 = \frac{\partial \bar{E}}{\partial (\log z_0)} = k \cdot T^2 \cdot c_v,$$

$$\therefore \frac{\overline{(E - \bar{E})^2}}{\bar{E}^2} = \frac{kT^2 \cdot c_v}{\bar{E}^2} = \frac{kT^2 c_v}{\bar{E}^2} \quad \dots \quad \dots \quad \dots \quad (55)$$

Similarly,

$$\begin{aligned}
 \overline{M^2} &= \frac{\sum_{E=0}^{\infty} \sum_{M=0}^{\infty} M^2 \cdot W(E, M) \cdot t_0^M \cdot z_0^E}{\sum_{E=0}^{\infty} \sum_{M=0}^{\infty} W(E, M) \cdot t_0^M \cdot z_0^E} \\
 &= \frac{1}{f(t_0, z_0)} \cdot \left\{ t_0 \cdot \frac{\partial}{\partial t_0} \right\}^2 \cdot \left\{ f(t_0, z_0) \right\} = \frac{1}{f(t_0, z_0)} \cdot \left\{ t_0 \cdot \frac{\partial}{\partial t_0} \right\} \cdot \left\{ \overline{M} \cdot f(t_0, z_0) \right\} \\
 &= \overline{M^2} + t_0 \cdot \frac{\partial \overline{M}}{\partial t_0} \\
 \therefore \overline{(M - \overline{M})^2} &= \overline{M^2} - \overline{M}^2 = \frac{\partial \overline{M}}{\partial \left(\frac{\mu}{kT} \right)} = kT \cdot \frac{\partial \overline{M}}{\partial \mu} \\
 \therefore \frac{\overline{(M - \overline{M})^2}}{\overline{M^2}} &= \frac{\overline{M^2} - \overline{M}^2}{\overline{M^2}} = \frac{kT}{\overline{M^2}} \cdot \frac{\partial \overline{M}}{\partial \mu} \\
 \therefore \frac{\overline{(N - \overline{N})^2}}{\overline{N^2}} &= \frac{kT}{\overline{N^2} \cdot m} \cdot \frac{\partial \overline{N}}{\partial \mu} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (56)
 \end{aligned}$$

Also one can obtain

$$\begin{aligned}
 \overline{n_r^2} &= \frac{\sum_{N=0}^{\infty} \sum_{E=0}^{\infty} \sum_{n_r=0}^N n_r^2 \cdot w'(E - n_r \epsilon_r, N_r - n_r) \cdot t_1^N \cdot z_0^E}{\sum_{N=0}^{\infty} \sum_{E=0}^{\infty} w(E, N) \cdot t_1^N \cdot z_0^E} \\
 &= \frac{1}{g_r(t_0, z_0)} \cdot \left\{ t_1 \cdot \frac{\partial}{\partial t_1} \right\}^2 \cdot \left\{ g_r(t_0, z_0) \right\}, \\
 \overline{n_r^2} &= \overline{n}^2 + t_1 \cdot \frac{\partial}{\partial t_1} \cdot (\overline{n}_r) \\
 \therefore \overline{(n_r - \overline{n}_r)^2} &= \overline{n_r^2} - \overline{n}^2 = t_1 \cdot \frac{\partial}{\partial t_1} (\overline{n}_r) = \frac{kT}{m} \cdot \frac{\partial \overline{n}_r}{\partial \mu} \\
 \therefore \frac{\overline{(n_r - \overline{n}_r)^2}}{\overline{n_r^2}} &= \frac{kT}{\overline{n_r^2} \cdot m} \cdot \frac{\partial \overline{n}_r}{\partial \mu} \quad \dots \quad \dots \quad \dots \quad \dots \quad (57)
 \end{aligned}$$

These are the usual formulae found in the treatises of Fowler (1936) and Tolman (1938).

XII. CONCLUSION.

In the above discussion, all usual results have been derived in the forms obtained by Fowler (1936). Also some subsidiary mathematical calculations are the same as those of Fowler. But the present method differs from that of Fowler

almost in all the essential points, of which the most important ones may be summarised in the following:

- (i) Here the entire discussion is based on a principle similar to the principle of maximum likelihood, whereas in Fowler's method the same is based on average properties.
- (ii) Here no approximation formula has been used, whereas in the latter, the approximation by the method of steepest descent is the kernel of the entire development.
- (iii) Here a parameter or a variable, which has no *ab initio* significance (physical or statistical), has never been introduced and so all quantities entering in the calculations are real; whereas, in the other, two parameters, which have been afterwards correlated to two important functions of thermodynamics, have been introduced as two complex quantities, helping the calculations of approximate values and so having no *ab initio* significance.

In the present investigation, the entire discussion of the behaviour of a thermodynamic system is made consistently with the general formalism of statistics. In this discussion, there is nothing which will restrict it to the thermodynamic systems only. So it is expected that the present method can be applied for discussions of essentially different types, viz. the problem of distributions of population and money in a country where M and E will represent the measure of the population and the money in the country.

Moreover it should be noted that the method, developed here, is essentially statistical and macroscopic, but can be applied to microscopic discussion with equal convenience and advantage.

ABSTRACT.

In this paper, an essentially statistical approach has been made to investigate the behaviour of a thermodynamic system. In the entire development, the problem has been discussed macroscopically as a statistical problem of general type. As in phenomenological thermodynamics, no assumption about the structure and the internal mechanism of the system has been introduced. For this, a probability of occurrence of the system, enclosed in a definite volume surrounded by a definite environment, in a state specified by definite values for quantities of matter and energy contained by it, is suitably defined and is taken to be the starting point of the present discussion. The analytical behaviour of the probability, considered as a function of two parameters—the characteristic parameters of distribution—has been investigated and it has been shown that this function has a unique maximum for a set of values of distribution-parameters controlling the energy-exchange and the matter-exchange with the environment. It has been assumed that the state, for which the probability of occurrence is a maximum, corresponds to the observed state, and the values of the distribution-parameters, corresponding to the maximum value of the probability, are taken to specify the state of the system in a definite environment. Thus, over and above, the unique set of values for quantities of matter and energy, a probability-distribution of matter and energy has been associated to every observed state of the system. After this, to consider the effect of variations in the environment of the system, the equation of continuity for energy and matter has been taken in suitable form. Some functions associated with the equation of continuity for energy (the first law of thermodynamics) and that of matter, have been identified as entropy, temperature, and the chemical potential of the system. In this connection, some discussions about reversible variations and about the principle of adiabatic invariance have been made. The non-decreasing properties of the entropy have been established. Usual formulae for fluctuations have been easily obtained. It has also been shown that the method is also suitable for obtaining the laws of microscopic distribution when usual assumptions about microscopic nature of the system are introduced.

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ON THE FLORAL STRUCTURE OF *SCYPHOSTEGIA*

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(Communicated by Prof. P. Maheshwari, F.N.I.)

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The genus *Scyphostegia* was founded upon the basis of a single collection of female plants from Mount Kinabalu, Borneo (Stapf, 1894). The genus, represented by the single species *S. borneensis*, was referred to the family Monimiaceae on account of a few superficial resemblances presented by the plant with the members of the family. For example, the foliage of *Scyphostegia* was compared with that of *Daphnandra repandula* F. v. M.; the so-called disc was interpreted to be homologous with the receptacle of the monimiaceous genera.

Engler (1897), in his supplement to the monimiaceae, considered *Scyphostegia* as a genus of dubious affinities. In a more detailed monograph of the family Perkins and Gilg (1901) excluded the genus from the Monimiaceae on account of the following reasons: (i) Absence of ethereal oil cells (a feature also recorded by Stapf), (ii) Tepals being inserted at the base of the receptacle, (iii) Carpel having scaly outgrowths at its base, and (iv) the inflorescence belonging to a basically different structural type from those met with in the Monimiaceae.

In 1926, Hutchinson created a new family, the Scyphostegiaceae, to accommodate the genus and tentatively placed the family in the Urticales. He further surmised that 'when male flowers are known this genus may be found to belong to Moraceae'.

The male plants of *Scyphostegia* were collected by J. Clemens and M. S. Clemens (field No. 26361) in the type locality of the female plant (Mount Kinabalu) nearly 40 years after Stapf's establishment of the genus, and was described in 1937 (Baehni). In the succeeding year appeared a contribution dealing with a more detailed study of the structure of the inflorescence and flowers in the male as well as in the female plants (Baehni, 1938). In this paper, the author disagreed for placing the family Scyphostegiaceae in the Urticales as was done by Hutchinson, and strongly felt that the genus 'ne peuvent pas etre places dans une position tres eloignee des Monimiacees'.

In the latest study dealing with the comparative morphology and relationships of the Monimiaceae (Money, Bailey and Swamy, 1950) *Scyphostegia* was found to possess a trilacunar nodal structure and a tricolpate type of pollen in contrast to the typically unilacunar nodal types and monocolpate, dicolpate or acolpate types of pollen characterising the Monimiaceae. On the basis of these features presented by *Scyphostegia*, as well as on the grounds that the genus furthermore differed from the other members of the family in the absence of ethereal oil cells and in the possession of a unique type of floral structure, the genus was excluded from the Monimiaceae. It was also suggested that a summation of the known anatomical and morphological characters of *Scyphostegia* do not indicate any relationship with the allied families of the Monimiaceae either.

In view of the fact that Baehni (1938), on the basis of floral structure, visualised a close relationship of the Scyphostegiaceae not only with the Monimiaceae but also with certain other putative ranalian families, an extended study of the reproductive structures—as limited by herbarium specimens—was undertaken in order to verify his contention. The results are incorporated in the present contribution.

Herbarium specimens bearing the following collector's name and number were available for study:

<i>Haviland</i> 1377	..	female (TYPE).
<i>Orolfo</i> 3079	..	female.
<i>Clemens</i> 26062	..	female.
<i>Clemens</i> 26361	..	male (TYPE).
<i>Burot Ho</i> 1758	..	male.
<i>Puasa</i> 3171	..	male.

INFLORESCENCE.

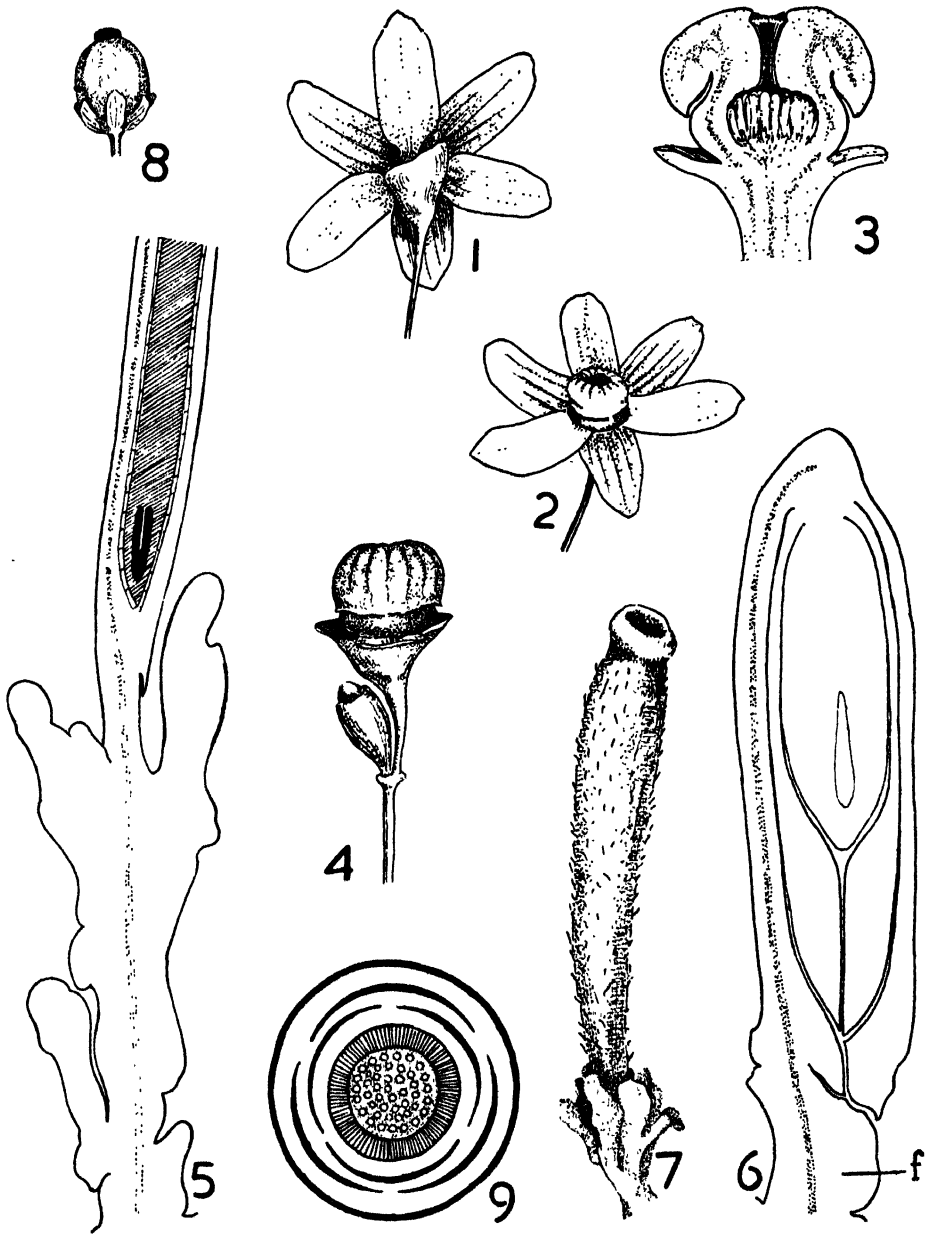
The male as well as the female inflorescences of *Scyphostegia* conform to one and the same structural plan. The lax raceme takes its origin from the leaf axil and gives out shorter lateral branches in a more or less alternating fashion throughout its length, the branch situated nearest to the leaf axil being the first to develop ontogenetically. Each branch at its apex bears a cluster of 5–10 flowers in the male and 5–8 in the female. A diagram of such a cluster as seen in serial transverse sections is reconstructed in Fig. 17. The central double cross-hatched circle represents the axis of a lateral branch of the inflorescence, the stippled circles the individual flowers, and the heavy circles the infundibulous bracts subtending the respective flowers. As may be appreciated from the relative sizes of the stippled circles, the outermost bract encloses the oldest flower, the one placed in its immediate interior the next younger flower, and so on (compare Figs. 18–20 for male, and Figs. 1 and 4 for female). In Fig. 18, a cluster of male flowers is shown as occurring *in situ* at the tip of a lateral branch of the inflorescence. When the outermost infundibulous bract is dissected out, the long slender pedicel of the oldest flower and the next younger flower in the axil of the first are exposed to view (Fig. 19); the removal of the bract of the second flower would in turn show the presence of the third flower bud (Fig. 20). That exactly a similar relationship holds for the female flowers may be seen in Fig. 1, which depicts an entire flower cluster and in Fig. 4, showing the next younger flower bud in the axil of the first. Thus each lateral branch of the inflorescence—whether in the male or in the female—has the construction of a raceme, although the flower-bearing part of the branch axis is greatly condensed. The inflorescence *as a whole* may rightly be interpreted as a compound raceme.

MALE FLOWER.

External morphology: The short pedicel of the young male flower (Fig. 20) becomes elongated into a slender structure nearly half as long as the perianth towards maturity (Figs. 19, 22). The perianth is united into a tube, the individual lobes becoming free about the mid-height of the flower (Figs. 19, 21). The lobes of the outer whorl are somewhat fleshy, three in number, and pronouncedly concave. The lobes of the inner set are again three, in alternating disposition in relation to the outer, thinner, and significantly smaller both in longitudinal and latitudinal dimensions (Fig. 21). The third inner whorl consists of three fleshy knob-like 'glands' taking their position opposite to the lobes of the second whorl (Figs. 22, 23). The innermost whorl is represented by three stamens that are confluent by their adaxial surfaces (Fig. 23). The dehiscence of the anthers is extrorse. The pollen grains are typically tricolpate (Fig. 24).

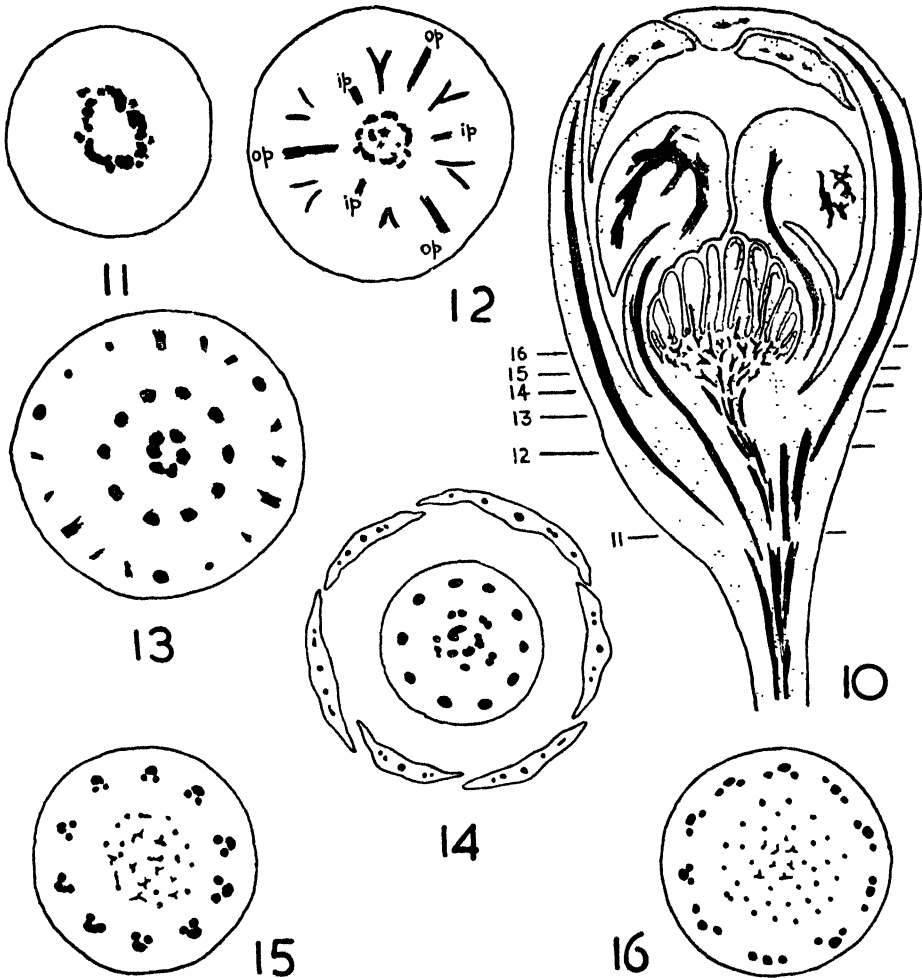
Anatomical structure: The pedicel contains two strands of vascular tissue (Fig. 26) each of which trifurcates below the insertion level of the perianth to give rise to six bundles¹ (Fig. 27). They soon arrange themselves in two whorls of

¹ The phraseologies employed here are purely descriptive of phenomena seen in successive serial sections and do not involve developmental implications of vascular tissues.



FIGS. 1-9: Fig. 1. Female flower as seen from the stalk end. Fig. 2. Same, as seen from above. Fig. 3. Median longisection of female flower; perianth removed. Fig. 4. Female flower (perianth trimmed off) after removal of the subtending infundibulous bract; note the flower bud in the axil of the flower. Fig. 5. Longisection (micropylar part) of an immature seed with its funicular outgrowths. Fig. 6. Longisection of an ovule at anthesis showing the pedestal-like funicle (*f*), two integuments, and crassinucellus with an outline of the female gametophyte. Fig. 7. A seed at the stage shown in Fig. 5, showing funicular outgrowths. Fig. 8. Mature fruit. Fig. 9. Floral diagram of the female flower.

three each (Fig. 28), the peripheral set of bundles later contributing to the vascular system of the outer whorl perianth lobes (Figs. 29–35). The three bundles of the inner set undergo trifurcation (Fig. 28) and one strand from each group moves out (Fig. 29) and occupies an alternating position with and in the same circumference of the bundles supplying the outer perianth whorl (Fig. 30). These strands vascularise the lobes of the inner perianth whorl (Figs. 33–35). The main bundle of the sepals and petals remains unbranched throughout the tubular part of the



Figs. 10–16: Fig. 10. Longisection of a female flower slightly before anthesis. Figs. 11–16. Transections of female flower at levels as indicated by corresponding numbers in Fig. 10.

perianth (Figs. 31–33) and splits up into the median and lateral veins only as the individual perianth lobes become separated (Figs. 34, 35). Vascularisation of the two outer whorls of the flower thus being completed, there remain in the centre of the floral axis three strands (Fig. 29). At a slightly higher level (Fig. 30) each of these divides by a tangential split. The outer three branches supply the corresponding 'glands' constituting the third whorl (Figs. 31, 32) and undergo some degree of proliferation into short branches (Fig. 25). The remaining three branches

constitute vasculature of the stamens (Figs. 25, 31–35). These bundles at the point of their origin are endarch as is the situation in other floral appendages, but after entering the anther assume exarch disposition.

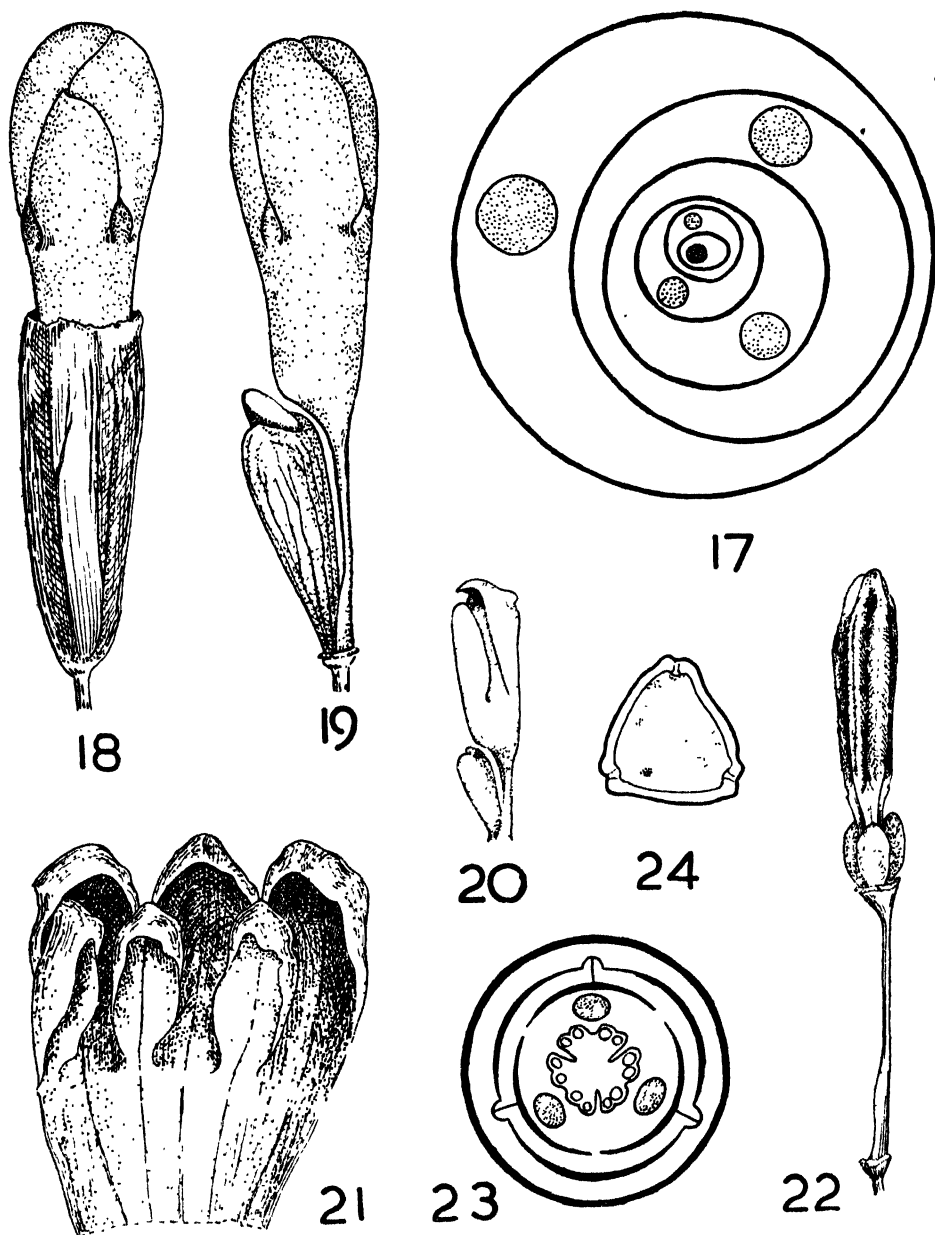
FEMALE FLOWER.

External morphology: Just like in the male flower, six perianth lobes in two alternating sets constitute the first and second whorls. In contrast, however, the lobes of both the whorls are not only free from the base, but also morphologically similar to each other (Figs. 1, 2). Furthermore, the resemblance is reflected in their histological structure as well. The lobes are somewhat fleshy with a toughened exterior and persist in the mature fruit (Fig. 8).

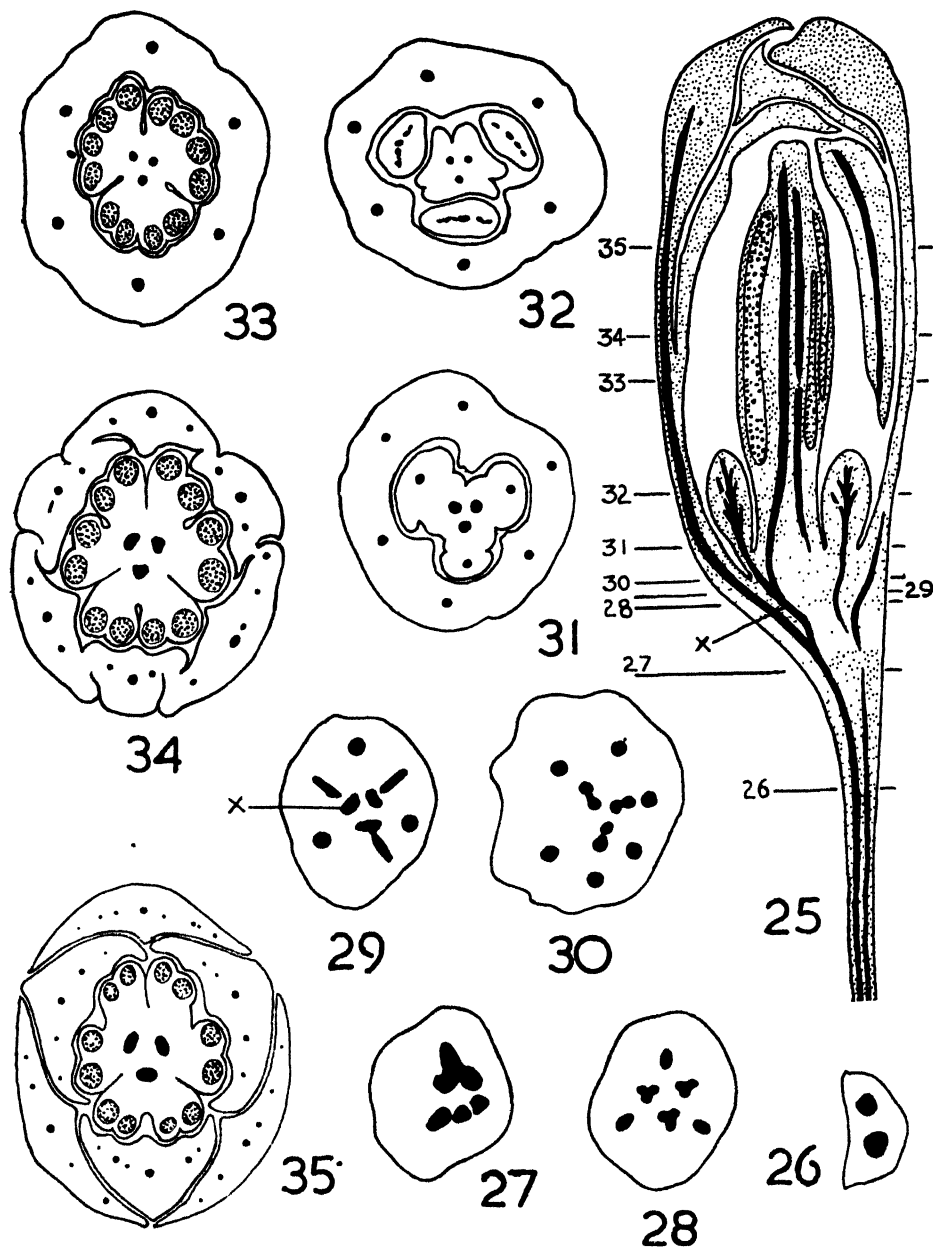
Structures corresponding to the third whorl of the male flower (the 'glands') are absent here. Instead, an urceolate structure occupies the position of this whorl (Figs. 2, 9) which at the same time is also the innermost. The free margin of this structure is pronouncedly deflexed so as to cover nearly the upper half (Figs. 4, 3). The exterior of the deflexed surface presents 8–12 longitudinally running ribs. The wall of the urceole is rather fleshy and encloses a single cavity that communicates with the outside through a narrow passage at the apex (Fig. 3). Two to four cell layers surrounding the passage show a conspicuously glandular texture, presumably a feature connected with the growth and passage of the pollen tube. Although the superficial cell layers of the extensive deflexed surface also present a more or less similar histological character, an examination of adequately preserved material of relevant developmental stages is necessary to confirm its stigmatic function or otherwise. The neck of the urceole is greatly compressed vertically and as such the gynoecium is devoid of a style. The floor of the urceolar cavity is slightly raised and functions as the placenta on which numerous anatropous ovules arise (Figs. 3, 10). In the prefertilisation stage the funiculus part of the ovule presents the appearance of a stub-like pedestal (Fig. 6, *f*), which later undergoes significant modifications as will be explained on a subsequent page. The ovule has two closely adpressed integuments, both of which take part in the organisation of the micropyle, and a fairly massive nucellus whose vertical dimension is nearly twice its width (Fig. 6).

Anatomical structure: In the basal part of the pedicel the vascular strands are arranged in the form of a somewhat irregular ring as seen in transverse sections (Fig. 11). As the two perianth whorls arise in close succession, the vascular strands supplying them also differentiate almost simultaneously at the same level (Fig. 12, *op*—outer perianth: *ip*—inner perianth). The main strand of each perianth lobe soon breaks up into the median and marginal bundles, the latter again branching into two whereby a transection at the base of a perianth lobe shows the presence of five bundles (Fig. 14). Higher up in the lobe the bundles undergo further ramification and webbing.

After the differentiation of strands for the perianth, the remaining vasculature soon resolves into two concentric systems of strands (Fig. 13). The outer ring consists of 8–12 strands (corresponding to the number of ribs present on the deflexed part of the gynoecium) and supply the wall of the gynoecium. During their course, each strand trifurcates into a central larger and two smaller bundles one on its either lateral side. This 'triplet' condition remains distinct even at higher levels of the gynoecium (Figs. 15, 16). At the region of the deflexed part, the bundles become rather massive, undergo considerable ramification and anastomoses, and form sprays in conformity with the deflexion (Fig. 10). The inner ring of strands (Fig. 13) consisting generally about half the number as that of the outer, almost immediately begin to undergo an extensive system of branching, the branches spreading rather uniformly in the floor of the gynoecium (Figs. 10, 14–16). Each ultimate branchlet of this system forms the vascular strand of an ovule (Figs. 10, 6).



FIGS. 17-24: Fig. 17. Diagram showing the plan of construction of inflorescence; double cross-hatched area—inflorescence axis; stippled areas—individual flower; heavy circles—infundibulose bracts subtending a corresponding flower. Fig. 18. A branch of male inflorescence, the basal region being enveloped by the infundibulose bract. Fig. 19. Same, bract removed; axillary bud is exposed. Fig. 20. Continuation of the inflorescence after the removal of involucre of the axillary bud in Fig. 19. Fig. 21. Perianth of male flower longitudinally split and spread in one plane, as seen from the abaxial side of the perianth. Fig. 22. Male flower after removal of perianth, showing three 'glands' and stamens. Fig. 23. Floral diagram of male flower. Fig. 24. Section of pollen grain at the equatorial region showing three germ pores.



FIGS. 25-35: Fig. 25. Longisection of a male flower just before anthesis. Figs. 26-35. Transverse sections of male flower at levels as indicated by corresponding numbers in Fig. 25.

FRUIT AND SEED.

During post-fertilization development, the ovules and ovary undergo considerable morphological modifications. The ovary develops into a fleshy pericarp, lodging within its cavity a large number of seeds, and thus the fruit of *Scyphostegia* may aptly be classified as a berry. The most significant modification appears to

be the change undergone by the funiculus. Keeping pace with the development of the fruit, the stub-like funiculus (Fig. 6) sends out spongy parenchymatous lobes towards the chalazal end of the seed. The lobes, often exhibiting a considerable degree of irregular branching, grow rapidly in the disposition of a whorl and envelope the micropylar region of the seed (Figs. 7, 5). It may be mentioned in passing that it is the inaccurate interpretation of these structures in the past that has been responsible not only for the misconception of the floral structure of *Scyphostegia* as a whole, but also for the diverse opinions expressed with regard to the systematic relationships of the family based on such misconceived premise.

The seed is vertically elongate, slender, and somewhat cylindric. When detached from the placenta (from herbarium specimens) it carries with it the whorl of funicular outgrowth (Fig. 7). The chalazal end shows a slight constriction, the apex being depressed; the histological features of this part of the seed could not be studied for want of suitably killed material. As far as could be ascertained from herbarium specimens after re-expansion, the seed coat appears to be formed essentially by the outer integument, the cells of its innermost layer having undergone vertical elongation and hardening. The outer surface of the seed becomes uniformly but sparsely distributed with unicellular trichomes (Fig. 7). No traces of the inner integument could be made out. The vascular strand of the ovule remains unbranched in the funicular region as well as in the tissues of the seed coat (Fig. 5). In the oldest stage available for examination, the seed cavity is filled with cellular endosperm and the young embryo lies near the micropyle (Fig. 5).

DISCUSSION.

Perianth of the male and female flowers: In both sexes the perianth consists of two whorls, the individual members of one whorl alternating with those of the second. In the male, the basal half of the perianth lobes is fused to form a single tube whereas in the female, the individual lobes are completely free; furthermore, in the male, the outer perianth members are unlike those of the inner in regard to size, shape and degree of succulence, but in the female all perianth appendages are exactly alike. In view of the distinctive characters exhibited in the two perianth whorls of the male flower, the outer whorl may presumably be regarded as sepaline and the inner, petaline. Stapf (1894) considered the outermost two whorls of the female flower as perianth, Hutchinson (1926) as 'bracts' or 'involucre', and Baeni (1938) as 'calyx'. Although there are no morphologically distinctive characters in the two outer whorls of the female flower, an interpretation of these structures on a homologous rank with those of the male flower fits harmoniously with the relation the perianth bears to its succeeding whorl. Whether the outer and inner whorls of the female flower should then be designated literally as sepals and petals in descriptive phraseology is a matter of personal opinion and is not of any direct consequence for an understanding of the true, fundamental nature and relation of other floral appendages. On the other hand, the term tepal could as well be employed if one prefers to do so, provided he appreciates the homology of the concerned structures in the flowers of the two sexes.

Baehni (1937, 1938) looks upon the outer two whorls of appendages (at present interpreted as calyx and corolla) of the male flower as 'gamosepalous corolliform calyx' and designates the third whorl (at present regarded to be 'glands') as 'petals'. This view does not appear to be in harmony with known facts: the appendages of the outer two whorls alternate with one another; those of the third whorl is opposite to the second (as well as to the fourth) (Fig. 23). Thus, petal, gland and stamen, which belong to successive whorls lie, along one and the same radius. The vascular supply too of these structures likewise arise by the branching of the pedicellar strands along the same radius, and more or less in a periclinal plane (compare Figs. 30 and 31). This situation does not lend itself to the interpretation that the

first two whorls (whose members are in alternating position) as sepals made up of six lobes and those of the next inner whorl, as petals. On the other hand, it would be in conformity with morphological and anatomical structure to regard the outermost whorl as constituting the sepals and the immediately next whorl as constituting the petals (Fig. 35).

The third whorl of the male flower: The morphological nature of the third whorl of the male flower ('petals' of Bachni) is rather intriguing. This is largely because of its positional anomaly in being directly opposite to the appendages belonging to the immediately neighbouring whorls on either side. There are no significant features in the external form of the appendages to suggest their petaline nature. Histologically, the structure appears to be made up entirely of homogeneous parenchyma cells and is supplied with a well-developed vascular bundle. Neither 'vestigial structures' nor rudimentary vascular traces either between the second and third whorls or between the third and fourth whorls are present; thus the possibility of looking for any suppressed whorls is eliminated.

It is important to recall at this point that the vascular supply to the calyx and corolla are derived from one set of strands of the pedicel and that the supply to the structures of the third whorl as well as to the stamens are derived from a common cord (marked \times in Figs. 25, 29). This feature affords evidence to a considerable extent for the surmise that the first two whorls belong to one morphological category and that the third and fourth together belong to a second morphological entity. In other words, if the 'glands' of the third whorl are to be morphologically compared to any other appendage of the flower, it is most nearly related to the stamens than to the petals. Then how to account for the derivation of the third whorl?

The superposition of the 'gland' and stamen is a serious obstacle to admit the possibility of interpreting the 'glands' as remnants of an outer whorl of stamens. If a way can be found to explain this anomalous position of the glands, it would indeed be a contribution towards a clearer understanding of the floral structure. Data obtained through studies on ontogeny of a structure and information gathered through comparative morphology and anatomy of corresponding structures or of their modifications in closely related species often provide significant clues for the elucidation of the real nature and identity of intriguing floral appendages. Neither of these procedures is possible for *Scyphostegia* at present, because no suitable material is available to undertake developmental studies and the systematic position of the genus is so notoriously uncertain that any assumptions as to its presumed alliance would be unfounded.

Reserving a final conclusion as to the exact *modus operandi* in the derivation of the extant structures of the male flower of *Scyphostegia* for future, a speculation involving a series of hypothetical phylogenetic stages may be visualised, the purpose of which is only to serve as a working hypothesis for later investigations and discussion. The ancestral type of the male flower is conceived as consisting of just three whorls,—an outermost whorl of three sepals, a middle whorl of three petals, and an innermost whorl of three stamens (*s*, *p*, *st*, respectively in Fig. 36 A) having the shape of a microsporophyll, that is, a more or less dorsiventrally flattened structure with a median and two marginal veins; that the pairs of sporangia were situated between the median and marginal veins; that the sporangia dehiscence in an extrorse manner and that the vascular traces in the sporophyll had an exarch orientation, that is, the protoxylem points turned away from the floral axis (Fig. 36 A).¹ Microsporophylls of this kind are not wholly hypothetical; they are seen in a considerable number of the ranalian genera that exhibit in their tissues and organs a relatively low level of structural specialisation phylogenetically.

¹ In this series of figures only one sector of the flower is shown as seen in transections.

Whether the stamens in the ancestral type of *Scyphostegia* were syngenesious or free is a point which is immaterial for the present.

Subsequent phylogenetic modifications of the ancestral type of microsporophyll involve a pronounced activity of the marginal meristem of the sporophyll with simultaneous curvature of the margins so as to overlap the thecae. As a concomitance there is a shift in the disposition and orientation of the marginal bundles (Fig. 36, B, C). Finally the margins fuse (Fig. 36 D), so also the two vascular

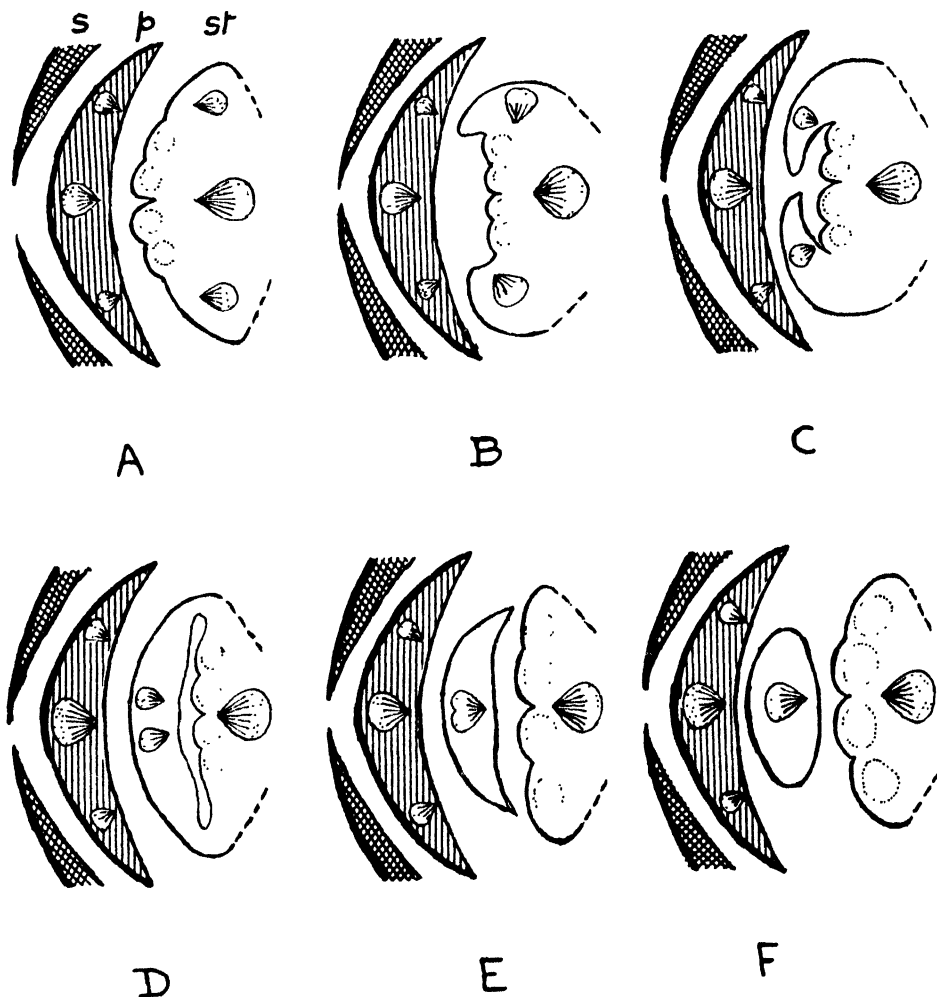


FIG. 36 A-F: Theoretical series of diagrams illustrating the derivation of the third whorl of the male flower. One sector of floral structures as seen in transection is shown. *s*—sepal, *p*—petal, *st*—stamen.

bundles therein (Fig. 36 E) and the newly formed adaxial part with its vasculature becomes detached from the sporangium-bearing part (Fig. 36 E). The final result of this series of changes is the interpolation of a new whorl consisting of three appendages that are placed on the same radius of the petal and stamen and between them (Fig. 36 F).

In the preceding hypothesis it will be seen that no attempt has been made to explain endarch orientation of the vascular bundle of the stamen. In fact such a situation has been assumed for the stamen of the ancestral hypothetical flower. Whether this situation preceded or followed the phylogenetic modifications surmised above, or was synchronous with them, does not interfere with the view suggested as to the anomalous position of the third whorl and as to how it might have been derived. That vascular bundles may often show various kinds and degrees of torsion or twisting not only in floral axes and their appendages but also in the vegetative axes and structures borne by them is a fairly common phenomenon although this fact seems to be not so well appreciated by anatomists who concentrate on the structures of only one part of the plant body, for example, on the flower. Furthermore, the behaviour of a vascular strand or bundle in regard to its orientation is quite often varied at different levels of one and the same structure. Thus at certain specific levels of a structure a bundle may be exarch and at certain other levels the same bundle may assume an endarch orientation. In the flower of *Scyphostegia* itself the staminal trace, soon after its formation, is endarch but assumes an exarch orientation only after entering the anther bearing part. Thus a certain mode of orientation of a bundle, in itself, may not be of much morphological significance.

With regard to the possible function of the structures belonging to the third whorl, no definite opinion can be expressed until suitably preserved material is examined. That the structures under consideration cannot be regarded as petals but that they are more nearly related to the stamens than to any other appendages of the flower makes one wonder if these modified parts of stamens could not have acquired some secondary function—as for example, a mechanism for the landing of the insect visitor, or as an organ for secretion of sugary solution, etc. Although in herbarium specimens the histological structure of these appendages fails to exhibit

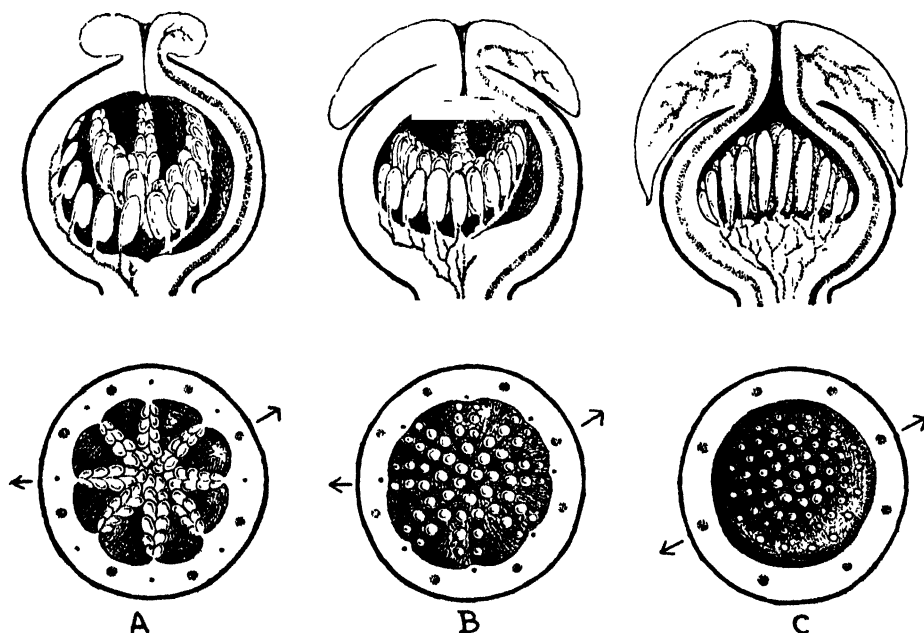


FIG. 37 A-C: Theoretical series of diagrams to illustrate the derivation of the extant gynoecium. In the upper series, the gynoecium is drawn as seen when cut longitudinally along the arrows in the lower series. In the lower series, transversely halved aspects of corresponding gynoecia are shown.

the typical characteristics of secretory tissues, the probability of their playing this rôle is not altogether ruled out. Because, examples of stamens bearing accessory appendages in the form of lobes, glands, etc., that are known to take part in the secretion of sugary fluids are not wanting in the angiosperms. Future investigations and field observations alone should settle whether the corresponding structures in *Scyphostegia* are of the nature of nectaries or a device for ensuring efficient pollen dispersal through an insect visitor. Tentatively they may be referred to as 'glands' for purposes of description.

The essential organ of the female flower: Conflicting opinions have been expressed as to the nature of the centrally situated urceolate structure of the female flower. According to Stapf (1894) it is a 'disc' or 'receptacle' lodging a number of 'carpels'; to Hutchinson (1926) the wall of the urceole represents a 'receptacle resembling thick corolla' the cavity of which is occupied with 'female flowers'; and Baehni (1938) equates the wall of the urceole with 'corolla' and the structures within it to 'carpels' (Fig. 38). With due regard to these botanists, it must be said that it is most unfortunate that the female flower of *Scyphostegia* has not received as critical an examination as it should have deserved in their hands. Had they only dissected out the younger stages of the internally borne structures of an urceole and observed them under the microscope, it is certain that they would have reached altogether different conclusions. In fact, it is as a consequence of their interpretations of these structures that the authors were forced to misconstrue the entire structure of the flower.

That the structures within the urceole are nothing but ovules themselves has been demonstrated on a previous page. Then it is but logical to regard the urceole as no other structure than the gynoeceum. Furthermore, there is every reason to regard the tissue in the immediate neighbourhood of the opening of the urceole—though not all of the deflexed, morphologically inner surface of the urceole—as being stigmatic. The next two whorls of appendages outside the gynoeceum would naturally fall in the category of tepals (Fig. 38).

The structure of the gynoeceum of *Scyphostegia* is rather remarkable, particularly in regard to the nature of placentation. If the number of ridges on the deflexed (stigmatic?) part of the gynoeceum, the number of lobations protruding from these ridges into the 'stylar canal,' and the number of main vascular strands that run in the wall, may be taken as reasonably reliable indicators of the number of carpels that have entered into its construction, then it has to be surmised that the gynoeceum is made up of several carpels, their number being between 8 and 12. On this premise there is every reason to believe that the extant situation is an end product of a particular trend of phylogenetic modification. It is conceivable that the ancestral form of the gynoeceum of *Scyphostegia* was multicarpellary and unilocular; that the placentation was parietal; that the youngest ovules were borne towards the apical end of the placentae and the oldest towards the base; that the median vascular bundles of the individual carpels, after traversing the wall of the gynoeceum, entered the more or less small capitate stigma and proliferated into a few slender branchlets; and that the marginal bundles, situated beneath the placentae gave off vasculature to the ovules (Fig. 37 A). Such a gynoeceum could have undergone phylogenetic specialisation on the following lines: (i) the placentae receded centripetally, that is, towards the floor of the locule, at the same time retaining the centrifugal order of maturation of the ovules; (ii) the median vascular bundles of the individual carpels did not undergo any profound changes excepting that their distal region in the stigma acquired a greater degree of proliferation and spread, obviously with its pronounced abaxial deflexion and expansion; (iii) the marginal bundles receded in conformity with the placentae towards the base of the locule and began to proliferate into the vascular traces of the ovules at lower levels of the gynoeceum (Fig. 37 B). A culmination of these modifications would result in a gynoeceum as seen in *Scyphostegia* (Fig. 37 C).

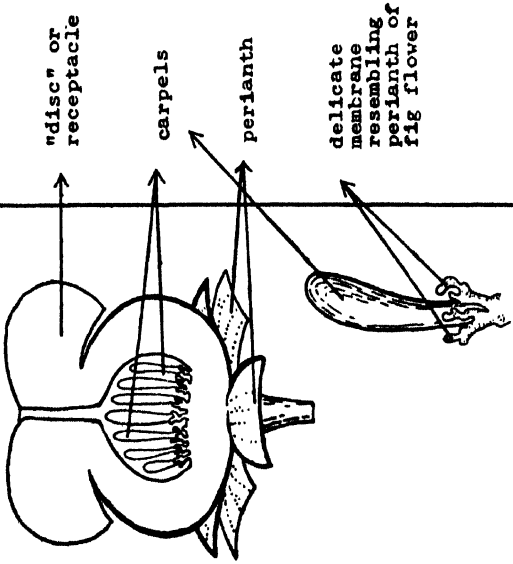
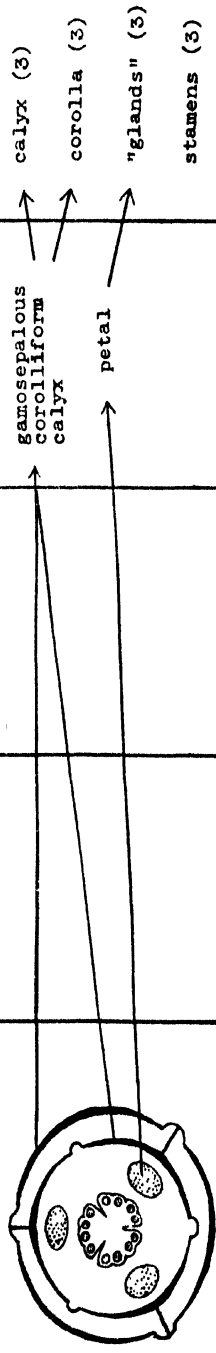
stapf	Hutchinson	Baehni	swamy
	receptacle resembling thick corolla female flowers involucre hyaline sepals	corolla carpels calyx trichomes	gynoecium ovules perianth (petals) funicular outgrowth
			

FIG. 38: Tabular diagram showing the interpretation of structure of the female and male flowers of *Scyphostegia* according to Stapf, Hutchinson, Baehni and the present author.

AFFINITIES OF *SCYPHOSTEGIA*.

Engler (1897) has treated the genus *Scyphostegia* as of 'unsicherer Stellung' under the Monimiaceae. Perkins and Gilg (1901) excluded the genus from the family (as also Money, *et al.*, 1950). After having accepted this procedure and after creating a new family, the Scyphostegiaceae, for the reception of the genus, two opinions have been expressed as to the relationships of the family—(i) that it could be related to the Moraceae (Hutchinson, 1926), and (ii) that it should be placed in a position not far removed from the Monimiaceae itself (Baehni, 1938).

In spite of viewing the male and female flowers of *Scyphostegia* in light of the new interpretations as given in the present contribution, the systematic position of the plant remains problematical. However, it has become increasingly clear that the combination of characters exhibited by this plant are so unique that there is ample justification to place the genus in a monotypic family of its own, the Scyphostegiaceae, as has already been done by Hutchinson (1926).

The monimieaceous affinity was contemplated essentially on the presumed homology between the urceolate structure of the female flower of *Scyphostegia* and the so-called receptacle of the monimieaceous flowers; and the urticaceous alliance on the interpretation of the internally borne structures of the urceole of *Scyphostegia* as true flowers. Now the genuine nature of the floral structure of *Scyphostegia* having been demonstrated, neither the suggested monimieaceous affinity nor the urticaceous relationship have any arguments in their favour.

A summation of anatomical, morphological and taxonomic characters of *Scyphostegia* affords strong supporting evidence to exclude the family from the above alliances, and also provides convincing arguments to negate a ranalian relationship. Speculations as to which other group of dicotyledons the plant is closely related should await the results of future investigations on the embryology, cytology, anatomy of the secondary xylem and phloem, and of other vegetative structures.

TAXONOMIC RE-DESCRIPTION.

In view of the foregoing critical re-examination and the new interpretation derived therefrom of the reproductive structures of *Scyphostegia* (see Fig. 38 for an epitome) it becomes necessary to amend the original descriptions of the family (Hutchinson, 1926), of the epithets of the genus and of the female flower (Stapf, 1894), and of the male flower (Baehni, 1937).

Scyphostegiaceae Hutchinson, Fam. Flowering Plants, I. Dicotyledons (1927) 229. emend Swamy.

Arbores dioeciae; Folia alterna, simplicia, exstipulata. Flores in recemis; Perianthium 6-lobatum, lobis in duobus circulis, ad basim connatis in floribus masculinis, perfecte liberis in floribus femineis. *Flos masculinus*: circulis tertius tribus glandibus repraesentatus; stamina 3, syngenesica; gynoeceum inchoatum nullum. *Flos femineus*: gynoeceum superior, multicarpellatum, uniloculare; placentatio basalis; ovula multa, anatropa, bitegumentaria; semina multa, excrescentiis funicularibus stipetem circumdantibus; seminis operimentum ex modificato integumento exteriori constans; embryon amplum, cotyledones 2, ovati; hypocotyledon brevis et tenuis.

Scyphostegia Stapf in Trans Linn. Soc. Ser. II. 4 (1894) 217. emend Swamy.

Arbores dioeciae; Folia alterna, chartacea, crenulata. Inflorescentia racemus multiplex. Flores bracteati, bractae infundibulares. *Flos masculinus*: Perianthium 6-lobatum, lobis forma tubuli in dividia parte inferiori unitis, in duobus circulis, tribus lobis exterioribus sepalinis, tribusque lobis interioribus petalinis;

circulus tertius ex tribus glandulibus lobis petalinis oppositis; stamina 3, longitudinaliter elongata, syngenesica secundum faciem adaxialem; filamentis brevissimis; antheris quadrilocularibus, extrorsis; gynoeceum inchoatum nullum. *Flos femineus*: Perianthium 6, persistens; membris perfecte liberis, forma et mensuro similibus, in duobus circulis alternantibus dispositis; stamina inchoata nulla; gynoeceum uniloculare, sine stylo, stigmate prominenter deflexo; placentatione basali; ovulis multis, bitegumentariis, anatropis; funiculis stylobatae similibus. Fructus bacciformis, semina cylindrica, tenuia, excrescentia lobata ex funiculo oriente circumdata circa terminum micropylare; seminis operimentum exterior pilosum; endospermum minutum; embryon amplum.

S. borneensis Stapf in Trans. Linn. Soc. Ser. II. 4 (1894) 218. emend Swamy.

Arbor dioecia, glabra, 3-8 m. alta, trunco 30-60 cm. ambitu, ramis gracilibus, obscure angularibus. Folia oblonga 6×3 , 10×4 , 12×4.5 cm. longa et lata, apicibus abrupte acuminatis, basibus rotundatis-cuneatis, marginibus tenuiter crenulatis; nervis lateralibus 6-9-jugatis, angulo circa 60° a nervo principali orientibus; nervis inter nervos laterales notabiliter horizontali directione currentibus. Inflorescentia multiplex racemus, ramis lateralibus floriferis valde densis; ramis masculinis 5-10 flores ferentibus; ramis femineis 5-8 flores ferentibus; floribus novellis bracteis infundibularibus fere complete obductis; bracteis masculinis ad anthesim 8-12 mm. longis, 2.5-3.0 mm. diametro in parte latissima; bracteis femineis 5-8 mm. longis, 3.5 mm. latis in parte distante. *Flos masculinus*: 1.0-1.3 cm. longus, 2.5-3.5 mm. latus; perianthium tubiforme ad basim, liberum in parte superiori 6-lobatum, tribus lobis exterioribus amplioribus, sepalinis; tribus lobis interioribus parvioribus, tenuioribus petalinis; glandes 3, parenchymaticae, petalis oppositae; stamina 3, 8-9 mm. longa, syngenesica, glandibus opposita, apicibus sterilibus in stipitiformibus et semicircularibus projectionibus terminantibus; sine filamentis definitis; anthera novella quadrilocularis tempore antheseos bilocularis, verticaliter extensiva, extrorsa. *Flos femineus*: 1.0-1.5 cm. longus, 1.6-1.8 cm. latus tempore antheseos; perianthii membra 6, 7-8 \times 3-4 mm. longa et lata, in duobus circulis, forma et mensura perfecte similia, patentia, persistentia, tempore fructificationis in unicum circulum accommodata; gynoeceum urceolatum, sessile, multicarpellatum, uniloculare cum 8-12 striis tenuibus et longitudinalibus, sine stylo, stigmate extensive deflexo cum 8-12 striis tenuibus; placentatio basalis; ovula multa, subcylindrica, anatropa, bitegumentaria; funiculum parenchymaticum, stipitiforme. Fructus bacca 2.0-2.3 \times 1.5-1.8 cm. longa et lata cum stigmate persistente; paries carpellaris carnosus, 4-5 mm. densus; semina multa, stipitata, cylindrica, leviter curvata, 8-10 mm. longa, 1 mm. lata, cum depressione leviter obliqua termino chalazali; stipes et terminum papillatis eccrescentiis ex funiculo orientibus involuta; seminis operimentum unicellulo ribus trichomatibus sparse coopertum; endospermum nullum vel vix ullum; embryon dicotyledoneum, seminis cavum fere explens, cum brevi lenique hypocotyledone.

British North Borneo: Mount Kinabalu—*Clemens* 26062 (female), August 11—September 31, 1931; near Koung, alt. 666.6 m. *Haviland* 1377 (female TYPE); Beltolan, *Oroflo* 3079 (female), April 10, 1933; Pony Trail-Mi Post, alt. 1,000-1,333.3 m., *Clemens* 26361 (male TYPE), September-November, 1931; *Puasa* 3171 (male), May 2, 1933; near Kinabatabgan, level land at Balu Puteh, *Burot Ho* 1758 (male), May 27, 1932.

SUMMARY.

A critical re-examination of the male and female flowers of *Scyphostegia borneensis* Stapf reveals the following structural features:

- (i) The male flower has four whorls of appendages, the first two whorls from outside representing the perianth, the three outer lobes sepaline, the three inner petaline;

appendages of the third whorl constitute three 'glands' placed opposite to the petals; the innermost whorl is made up of three syngenealous stamens, lying again in a superposed seriation with the petals and glands.

- (ii) The female flower consists of three whorls of appendages, the outer two being homologous with the perianth of the male flower; the innermost whorl is the multicarpellary, unilocular gynoecium itself, lodging many ovules.

There are objections to regard the appendages belonging to the third whorl of the male flower as petals. Arguments are provided to interpret these structures as 'glands' that have been derived from microsporophylls. Theoretical stages in their phylogenetic derivation are reconstructed.

Understanding of the structure and nature of the essential organ of the female flower by previous botanists is shown to be erroneous. What they interpreted as 'disc', or 'receptacle', or 'corolla' is demonstrated to be no other structure than the gynoecium; what they thought to be 'carpels', or 'flowers' are shown to be the ovules. Hypothetical series of probable phylogenetic changes involved in the derivation of the extant situation in the gynoecium of *Scyphostegia* is illustrated.

In view of these significant re-interpretations of structure and morphology, the taxonomic descriptions of the family, genus, and species are amended.

From a totality of evidence obtained from a study of morphological and anatomical characters, any relationship of the family *Scyphostegiaceae*, either with the *Monimiaceae*, or with the *Urticaceae*, or with any of the ranalian families is strongly negated.

ACKNOWLEDGEMENTS.

I thank the authorities of the Arnold Arboretum, Harvard University, U.S.A., and of the Royal Botanic Gardens (Kew), England, for their courtesy in allowing me to examine the specimens in their respective herbaria. I am deeply indebted to the National Institute of Sciences of India for the award of a Senior Research Fellowship during the tenure of which this investigation has been carried out, and to Prof. T. S. Sadasivan and to the Madras University for making available to me, unreserved facilities for work in the University Botany Laboratory, Madras.

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A CORRECTION.

In Fig. 38, last column, line 7 from bottom, read (tepals) instead of (petals).

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COMMENTS ON *ASCARINA ALTICOLA* SCHLECHTER

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(Communicated by Prof. P. Maheshwari, F.N.I.)

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Ascarina alticola Schlechter was contrasted with other species of the genus as being characterised by the possession of a brown-tomentose inflorescence and of a very large female flower (Schlechter, 1906). However, the author added a note of warning to the effect that since the male flower, in spite of ardent search, had not been found, the question still remains open whether here we are not dealing with a representative, perhaps to be credited to another genus. In the course of a taxonomic revision of the genus *Ascarina* Forst. (Chloranthaceae), which is under preparation, *A. alticola* was found to exhibit several significant characters besides those mentioned by Schlechter that lie clearly outside the limits of those possessed by the genus as a whole. Subsequent detailed anatomical studies of the xylem, node, leaf, and flower of this species have contributed additional information to substantiate Schlechter's doubts and also have provided valid arguments to exclude the species not only from the genus, but also from the family. A critical evaluation of the data on hand towards the true identity of the species in question is presented in this paper.

Schlechter recognised *A. alticola* on the basis of a herbarium specimen bearing No. 15326, collected by himself from Mount Humboldt in South-Bezirk, New Caledonia. A duplicate specimen bearing the same number and collector's name in the herbarium of the Arnold Arboretum, Harvard University, has formed the material for the present study.

VEGETATIVE CHARACTERS.

The conspicuously coriaceous leaves of *Ascarina alticola* are arranged on the stem in verticils or sub-verticilis in contrast to the relatively thin leaves and decussate phyllotaxy of other species of *Ascarina*. The petiolar bases of opposite leaves in the latter category fuse with each other to form a vaginate structure sheathing the node; and denticular emergences of stipular nature arise from the free margin of the sheath. These features are absent in *A. alticola*, and the exstipular and clearly petiolate leaves are attached directly to the stem.

The stomata in the leaves of *A. alticola* are confined to the lower epidermis and are of the 'haplocheilic' type, i.e., each stoma is surrounded by four or five ordinary epidermal cells (Fig. 5). Although *A. alticola* resembles other species of *Ascarina* in these respects, the walls of the guard cells towards the mesophyll show a conspicuous thickening (Fig. 6), a feature that is absent in other species of *Ascarina*. The internal structure of the leaf of *A. alticola* reflects certain characteristics that recall relatively xerophytic modifications. Thus, the upper epidermis is covered over by a conspicuously thick cuticle; two or three well developed and compactly arranged layers of palisade cells are aligned beneath the epidermis; and, the mesophyll consists of small spherical cells, two or three layers next to the lower epidermis being arranged very compactly (Plate I, Fig. 4). In other species of *Ascarina*, the cuticular coating on the upper epidermis is very thin; a morphologically typical palisade layer is wanting, its place being occupied by loosely arranged, armed

parenchymatous cells; and, the mesophyll consists of irregularly shaped cells with conspicuous inter-cellular spaces. 'Ethereal oil cells' of the ranalian type that so characteristically occur in all species of *Ascarina* is totally absent in *A. alticola*.

The node of *A. alticola* is typically trilacunar, the median vascular strand of the leaf being larger than the laterals in contrast to the stereotyped situation in other species of *Ascarina*, where two strands of equal size are related to a single 'gap'.

The relatively thick bark of young twigs of *A. alticola* shows two distinct zones,—an outer, well-developed cork cylinder of radially seriate cells and an inner, more or less homogeneous appearing zone made up largely of parenchyma amidst which are scattered isolated sclereids and crystalliferous cells (Plate I, Fig. 3). The comparatively thin bark in corresponding samples of other species of *Ascarina* is characterised by the absence of cork formation and by the presence of sclerenchymatous sheaths confronting the fascicular parts of xylem; furthermore, the vascular rays undergo excessive widening in the bark, a feature that is wanting in *A. alticola*.

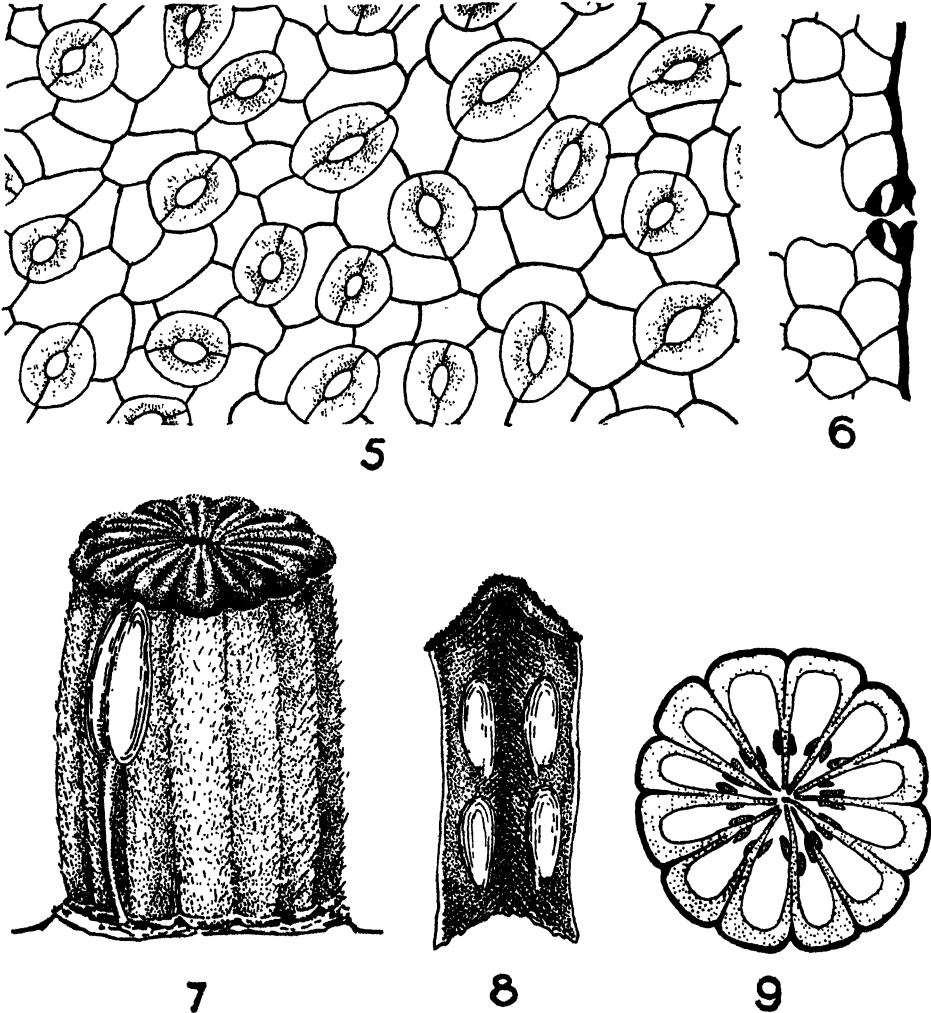
The early formed secondary zylem of *A. alticola* simulates in some points the situation seen in other species of the genus. The vessels are relatively long with steeply inclined perforated facets bearing numerous scalariform openings. However, the average number of bars in *A. alticola* is 50 whereas in other species of the genus it is 130. As seen in a transverse section, the wood is diffuse porous although at times the pores exhibit a tendency for arranging themselves in short radially oriented chains (Plate I, Fig. 1). The inter-vascular pitting in species of *Ascarina* and also in *A. alticola* fluctuates from scalariform and transitional stages to opposite and opposite arrangements; so also the vessel-ray and vessel-parenchyma pits. Species of *Ascarina* possess a heterogeneous type of ray structure, the multiseriate rays originating from the inter-fascicular parts, and uniseriate rays radiating from the fascicular parts. On the other hand, *A. alticola* appears to exhibit a conspicuous tendency towards the total elimination of the multiseriate rays leaving only the uniseriate ones (Plate I, Fig. 1). Thus, as seen in tangential sections (Plate I, Fig. 2) the wood contains uniseriate rays alone, although a few of them may be partly biseriate. In the older wood specimens of *Ascarina* the multiseriate rays (10 to 12 cells wide) predominate due partly to the widening of the primary uniseriate rays and partly to the splitting of the primary multiseriate rays into shorter ones; the secondary rays also exhibit a similar ontogenetic modification. In contrast, the mature wood of *A. alticola* maintains a dominating proportion of uniseriate rays, the multiseriate ones (3 to 4 cells wide) occurring rather occasionally. As in *Ascarina*, the xylery parenchyma in *A. alticola* is apotracheal and is distributed in diffuse-in-aggregate patterns as seen in transverse sections (Plate I, Fig. 1). The imperforate tracheary cells of species of *Ascarina*, as also of *A. alticola*, possess relatively thick walls and the pitting shows transitions from large oval or circular bordered pits with included apertures to those with reduced borders with slightly extended apertures.

FLORAL CHARACTERS.

The inflorescence and floral parts of the genus *Ascarina* are glabrous, whereas in *A. alticola* they are covered with a brown tomentum, the hairs being unicellular. In *Ascarina* the plants are dioecious. Schlechter presumed that *A. alticola* also had the same type of sex expression, but a careful re-examination has revealed that this species bears bisexual flowers.

In *Ascarina* the flowers are completely devoid of a perianth, the monocarpellary gynoecium or the single stamen being subtended directly by one or three bracts depending upon the particular species in question; the ovary is globose or ovoid containing a single orthotropous ovule; the sessile stigma is unequally two-lipped, the adaxial lip protuberant, being surrounded at its base by the crescent-

shaped abaxial lrp; the stamen is somewhat cylindrical, sessile, the 'connective' slightly projecting distally beyond the thecae in the form of a blunt, dorsiventrally flattened cone. The pollen grains are typically monocolpate. *A. alticola* presents totally contrasting characters in all these respects. The flower has a perianth whorl of two imbricate lobes that are, however, caducous, which feature obviously led Schlechter to use the designation 'floribus femineis nudis'. The androecium consists of a whorl of 8-12 stamens. The stamen shows a clear distinction into



TEXT-FIGS. 5-9.

'filament' and anther, the latter being basifixed on the former; and the 'connective' does not project beyond the thecae (Fig. 7). The pollen grains are typically tricolpate. The gynoecium is barrel-shaped (Fig. 7) and consists of 8-12 conduplicate carpels, the individual carpels conjointed laterally (Fig. 9). The true margins of carpels appear to be fused with one another and also perhaps with the axial tissue in part at lower levels, but are almost free at the ovule-bearing part (Fig. 9) and

apex. Each carpel lodges four anatropous ovules (Fig. 8). The stigma is sessile and conduplicate.

DISCUSSION.

It is evident from the preceding comparison of morphological and anatomical characters of the species of *Ascarina* on the one hand, and of *Ascarina alticola* on the other, that the two categories exhibit remarkably contrasting sets of characters that are indicative of highly divergent trends in evolutionary modifications. A summation of these characters clearly negate the inclusion of *A. alticola* in the genus *Ascarina* Forst. Furthermore, data (unpublished) obtained through comparative morphological and anatomical studies on the Chloranthaceae as a whole demonstrate that *A. alticola* does not bear any relationship to this family either. What then could be the probable affinities of *A. alticola*?

The combination of exomorphic and anatomical characters of *A. alticola* appears to suggest a general relationship to certain of the trilacunar families included in the order Parietales as conceived in the Englerian system. In fact, the plant bears in every detail unmistakable duplication of the anatomical features found in *Paracryphia* (Baker, 1921) of the Eucryphiaceae; and the morphological characters of *A. alticola* compare with those of *Paracryphia* to such a close degree that one is led to merge the former species in the latter genus. It is a matter of gratification to a student of comparative anatomy to find that a leading plant taxonomist, Dr. van Steenis, working independently, has arrived at a similar conclusion very recently (1950) and has proposed the necessary new combination, *Paracryphia alticola* (Schlechter) Steen.

In his 'Revision of the Eucryphiaceae' Bausch (1938) questions the inclusion of *Paracryphia* in this family. According to him, *Paracryphia* differs from *Eucryphia* in the 'subcalyptrate, caducous perianth segments, character of inflorescence, sessile stigmas, small number of stamens, absence of the shortly tubular effigurations of the thalamus, verticillate leaves, uniseriate ovules, etc.' He furthermore suggests that 'possible allies could be the Winteraceae (*Drimys*, *Illicium*) and Trochodendraceae'. It is yet to be determined through intensive comparative investigations of the various tissues and structures of the representatives of the Eucryphiaceae to realise how far these dissimilar characters between *Paracryphia* and *Eucryphia* are of significance in excluding the former genus from the family. But with reference to the suggested alliance of *Paracryphia* with either the Winteraceae, Illiciaceae, or Trochodendraceae, it must be plainly stated that the information on hand about these families (Bailey and Nast, 1945a, b; 1948; Nast and Bailey, 1945) only serves to negate such relationship quite emphatically.

SUMMARY.

A critical re-examination of *Ascarina alticola* Schlechter from anatomical and morphological points of view and a comparison of the data obtained therefrom with other species of the genus *Ascarina* and also with other representatives of the Chloranthaceae indicates that the species under consideration exhibits numerous significant differences that necessitate its exclusion not only from the genus *Ascarina*, but also from the family. On the other hand, the species proves to be congeneric with *Paracryphia* of the Eucryphiaceae.

ACKNOWLEDGEMENTS.

I thank Prof. T. S. Sadasivan and the Madras University for extending me the privilege to work in the University Botany Laboratory. The Research Fellowship awarded to me by the National Institute of Sciences has made this investigation, among others, possible and I am much obliged to the concerned authorities. I am grateful to the Arnold Arboretum for allowing me to examine the material in their collection.



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LEGEND TO FIGURES.

PLATE I. *Paracryphia alticola* (= *Ascarina alticola*) Fig. 1. Transection of young secondary xylem, $\times 176$. Fig. 2. Tangi-longisecton of the same, $\times 84$. Fig. 3. Transection of young bark, $\times 53$. Fig. 4. Transection of leaf, $\times 104$.

TEXT-FIGURES 5-9. *Paracryphia alticola* (= *Ascarina alticola*) Fig. 5. Surface view of lower epidermis of leaf showing the nature and distribution of stomata, $\times 180$. Fig. 6. Transection of a stoma, $\times 180$. Fig. 7. Gynoecium after removal of perianth and all stamens excepting one, $\times 50$. Fig. 8. An isolated carpel split open along the ventral 'suture' to expose the interior showing four ovules, $\times 50$. Fig. 9. Transection of gynoecium at the level of ovule-bearing region, $\times 50$.

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THE ${}^5\Pi-{}^7\Sigma$ ELECTRONIC TRANSITION IN MnBr AND MnF

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In a previous communication, the author 1952 has reported the analysis of the γ system of MnCl in the region λ 4800–5100 on the basis of an electronic transition ${}^5\Pi-{}^7\Sigma$. Analogous systems mentioned earlier by Mesnage (1938), Müller (1943) and Bacher (1948) in MnBr and MnF are studied by the author in detail and the results obtained are reported in the present paper.

EXPERIMENTAL.

The experimental set up is the same as the one used for manganese chloride and described previously (Author, 1949). Even in the case of manganese fluoride, a discharge tube of the same design was used to reproduce the system. The current flowing through the discharge tube is adjusted in such a way that no SiF bands were recorded on the plates. A Fuess glass instrument with an average dispersion of 30 Å per mm. in the region studied, was used for photographing the spectra. Exposures using Ilford Selochrome plates varied from half to two minutes' duration.

PLATE.

In Plate, Fig. I, which is a reproduction of the γ system of MnBr, the bands are apparently arranged in three groups. Starting from the red end, these groups are obviously to be regarded as the $\Delta v = -1$, 0 and $+1$ sequences respectively. The $\Delta v = 0$ sequence is better developed than the remaining sequences and is therefore examined for studying the multiplet structure.

Fig. II is a reproduction of the γ system of MnF occurring in the region λ 4900–5000. The $\Delta v = -1$ and $+1$ sequences are completely absent in the system.

STRUCTURE AND ANALYSIS OF THE BANDS.

MnBr.

The possible rotational heads and the scheme of the transitions to be expected in a ${}^5\Pi-{}^7\Sigma$ electronic transition are fully described in the previous paper. With reference to the figure of transitions given there, the vibrational and rotational assignments for the γ system in MnBr are given in Table I. The intervals between the members of the $\Delta v = 0$ sequence and those of the other groups suggest that the vibrational frequencies ω'_e and ω''_e are of the order of 255 and 288 wavenumber units respectively. The bands in the $\Delta v = 0$ group whose assignments are not shown in Table I belong to forms with $\Delta K = 0, 2$ or 3 in each F level. A sufficient number of bands are not developed in each of the other groups their assignment is not shown.

TABLE I.

MnBr Bands. γ System.

Sequence.	Wave-length.	Wave-number.	I	ΔJ		
				-1	0	+1
$\Delta v = -1$	5086.9	19652.9	4			
"	5077.1	19690.8	3			
"	5069.0	19722.3	5			
"	5063.7	19742.9	1			
$\Delta v = 0$	5041.9	19828.3	2		R_{Q_1}	R_{12}
"	5025.3	19893.8	1	$R_{P_{21}}$	Q_2	R_{23}
"	5021.0	19910.8	7			
"	5007.9	19962.9	6	$R_{P_{32}}$	R_{Q_3}	R_{34}
"	4993.9	20018.9	10			
"	4991.0	20030.5	5	$R_{P_{43}}$	R_{Q_4}	R_{45}
"	4986.5	20048.6	6			
"	4974.2	20098.1	1	$R_{P_{54}}$	R_{Q_5}	R_{56}
$\Delta v = +1$	4930.8	20275.0	2			
"	4928.8	20283.3	3			
"	4924.5	20301.0	2			

The intervals between the R heads of the $\Delta v = 0$ sequence shown in Table II indicate that the value of the coupling constant A is approximately 68.

TABLE II.

v', v''	R_{56}	R_{45}	R_{34}	R_{23}	R_{12}
0, 0	20098.1	20030.5	19962.9	19893.8	19828.3
		67.6	67.6	69.1	65.5

MnF.

For the γ system in MnF , the assignments for members of the $\Delta v = 0$ sequence were shown in Table III. As in MnBr , the rotational assignments are shown for the R heads only. The intervals between the R heads shown in Table IV suggest that the coupling constant A is of the order of 35.

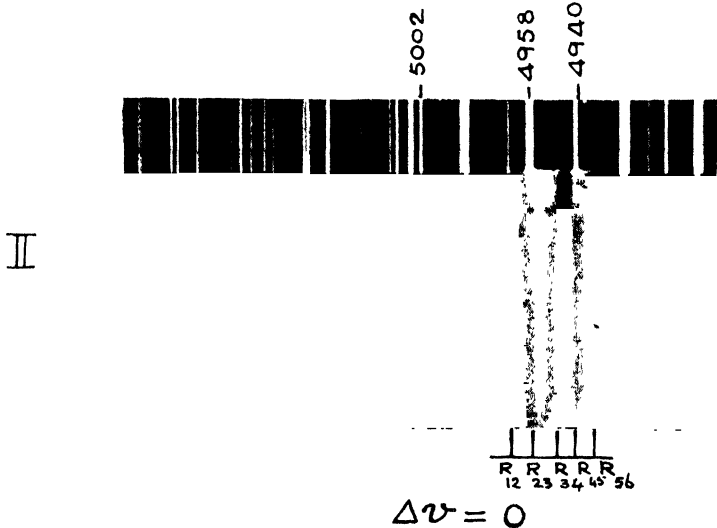
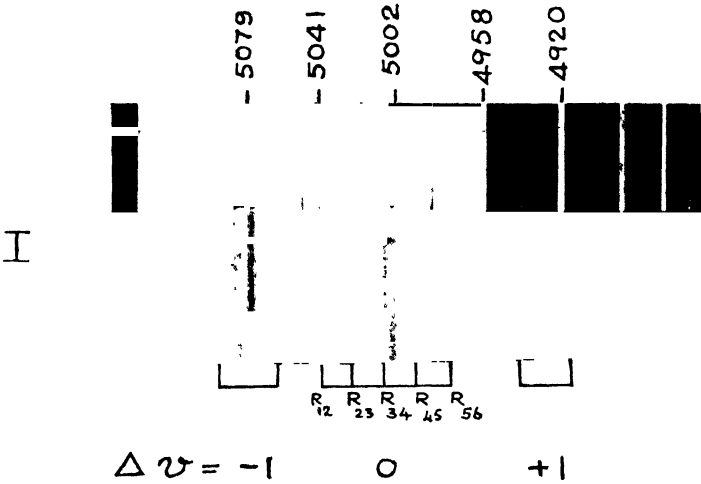


Fig. I. MnBr Bands (γ System)
Fig. II. MnF

TABLE III.

MnF Bands. γ System.

Sequence.	Wave-length. \AA	Wave-number. cm.^{-1}	1	ΔJ		
				-1	0	+1
$\Delta v = 0$	4964.4	20137.8	5		RQ_1	R_{12}
"	4958.0	20163.8	8			
"	4955.7	20173.2	9	RP_{21}	RQ_2	R_{23}
"	4952.3	20187.0	10			
"	4947.3	20207.4	7	RP_{32}	RQ_3	R_{34}
"	4941.8	20229.9	3			
"	4939.2	20240.6	10	RP_{43}	RQ_4	R_{45}
"	4936.5	20251.6	9			
"	4933.2	20265.2	6			
"	4931.2	20273.4	5	RP_{54}	RQ_5	R_{56}

TABLE IV.

v', v''	R_{56}	R_{45}	R_{34}	R_{23}	R_{12}
0, 0	20273.4	20240.6	20207.4	20173.2	20137.8
		32.8	33.2	34.2	35.4

ABSTRACT.

The emission spectra of MnBr and MnF were excited in a heavy current discharge through the vapour and photographed in the visible region using a Fuess glass spectrograph. The γ system in each of these molecules has been interpreted on the basis of a ${}^5\Pi-{}^7\Sigma$ transition, as in the case of a similar system in MnCl .

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ON A NEW METHOD OF DETERMINING THE THERMIONIC CONSTANTS OF MOLYBDENUM—I

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(Communicated by Dr. B. N. Srivastava, F.N.I.)

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1. INTRODUCTION.

Nearly all the investigations on the thermionic constants of metals are based on the pioneer work of O. W. Richardson in which the electronic emission, i , from a filament of the metal under investigation heated in vacuum to a temperature T , is measured and the constants A and ϕ of the equation

$$i = AT^2 \exp(-\phi/kT)$$

are determined. Such determinations suffer from certain defects.

According to the simple thermodynamic theory of thermionic emission by Dushman, A in the above equation is equal to $A_0(1-r_e)$ where $A_0 = 4\pi m\epsilon k^2/h^3$, r_e is the external reflection coefficient for the electrons incident on the metal, and ϕ is the heat of evaporation of the electrons at the absolute zero. According to the Fermi-Dirac statistical derivation of Sommerfeld, which is more rigorous, $A = A_0(1-r_i)$, where r_i is the internal reflection coefficient for electrons, but ϕ now becomes the work function at the temperature T . In the latter case however ϕ depends on the temperature but if this temperature dependence is ignored, the two formulae become identical if $r_i = r_e$, a relation which actually holds. As has been shown by Becker and Brattain (1934), the reflection coefficient is less than 0.1 and the experimental value of A is not usually accurate to within 10%. In principle, however, the filament type of experiments serve to determine $A_0(1-r)$ or $A_0(1-r) \exp[-(e/k)(\partial\phi/\partial T)]$ if ϕ is assumed to be a function of T and r independent of T (Herring and Nichols, 1949). From this the exact value of A_0 cannot be determined as, theoretically, the value of r is almost incapable of being determined under the experimental conditions.

Then, from the experimental point of view also, some difficulties arise. Formerly, as a result of the rigorous process of degassing by heating with d.c., the filament used to get pitted so that the cross-section varied from place to place and the exact area of the emitting surface was difficult of determination. Now heating is done by a.c. and the surface remains smooth. But, nothing can prevent evaporation of the metal from the surface of the filament so that the cross-section may yet vary from place to place. This may result not only in a non-uniform temperature and emission, but also in complications in the corrections for lead losses, Schottky effects, etc.

Further, the measurement of the filament temperature has its own difficulties. Although tables of emissivities are now available, a temperature scale for each metal to be investigated has to be set up under conditions of heat treatment as nearly identical as possible with those used in the measurement of the electron emission. Since conditions of heat treatment vary from sample to sample and, in the event of crystallisation of the metal occurring, from point to point even in the same sample, an element of uncertainty in the value of the temperature creeps in.

In the correction for the Schottky effect we have to use the equation

$$\log_{10} i_1 = \log_{10} i_0 + 1.905(F_e)^{1/2}/T$$

where F_e is the external field at the emitter in volts/cm. F_e can be calculated in terms of the applied voltage provided that the space charge distribution is accurately known. The accurate calculation of the space charge distribution for any given disposition of the electrodes is a difficult problem. For the simple case of a heated straight filament surrounded by a coaxial cylindrical anode the theoretical investigations, as pursued by Langmuir (1913), Langmuir and Blodgett (1923), and others, could give the space charge distribution only for the idealised case of the velocity of the electrons emitted being zero—an assumption unrelated to facts, since the emitted electrons are known to have a Maxwellian velocity distribution.

The present report deals with a new method of determining the thermionic constants of metals, and the constants of molybdenum have been found. A further communication will deal with the results obtained on Iron and Graphite by the same method. It will be seen from the present report that the new method has certain distinct advantages and is free from the defects mentioned above in the usual filament type of experiments.

A. S. Bhatnagar (1944) has determined the thermionic work function of graphite from the rate of effusion of electrons through a tiny hole in an otherwise closed hollow cylinder made from a rod of graphite heated electrically in vacuum to various high temperatures.

It is obvious that if we make a similar cylinder of molybdenum and heat it, then, for any given temperature, the electron gas produced in the metal chamber will attain a saturation pressure in equilibrium with the walls of the chamber and that the rate of effusion of the electron gas through the hole will be proportional to this pressure. If the effused electrons are collected by a Faraday cylinder with a limiting diaphragm of radius, r , placed at a distance, d , from the effusion hole of area, S , the saturation current, i_0 , has been shown by B. N. Srivastava (1938) to be given by

$$p = (2\pi mk)^{1/2} \cdot (r^2 + d^2) \cdot i_0 \cdot T^{1/2} / \epsilon S r^2 \quad \dots \quad (1)$$

where p is the equilibrium pressure of the electrons within the cavity and e , m , k , and T are the electronic charge and mass, the Boltzmann constant, and the absolute temperature, respectively.

The effect of the space charge on the electronic current under such an arrangement of apparatus has been worked out theoretically by Srivastava and Bhatnagar (*a*, 1944) and the conclusions derived have also been experimentally verified by them (*b*, 1944).

Now, applying the Clausius-Clapeyron equation to the equilibrium vapour pressure of a monatomic gas, the electronic gas pressure within the cavity of the molybdenum cylinder is given by (Jones, 1936).

$$p = e^c T^{3/2} e^{-\epsilon\phi/kT} \quad \dots \quad (2)$$

where ϕ is the work function, and c the chemical constant of the electron gas.

Hence $\log_{10} p/T^{3/2} = -\epsilon\phi/kT \log_{10} e + c \log_{10} e$.

Substituting the value of p from (1), we get

$$\log_{10} i_0/T^2 = -\epsilon\phi/kT \log_{10} e + c \log_{10} e - \log_{10} (2\pi mk)^{1/2} (r^2 + d^2) / \epsilon S r^2 \quad \dots \quad (3)$$

so that, as usual, if the experimental values of $\log_{10} i_0/T^2$ are plotted against the corresponding ones of $1/T$, the slope of the curve gives the value ϕ of the work function.

Now, since according to Sackur and Tetrode

$$e^c = 2(2\pi)^{\frac{3}{2}} k^{\frac{3}{2}} m^{\frac{3}{2}} / h^3,$$

$$\therefore c \log_{10} e - \log_{10} (2\pi mk)^{\frac{1}{2}} (r^2 + d^2) / \epsilon S r^2 = \log_{10} 4\pi m k^2 \cdot \epsilon S r^2 / h^3 (r^2 + d^2).$$

But $4\pi m k^2 / h^3 = A_0$, the thermionic constant in Richardson's T^2 equation. Hence, the above becomes equal to

$$\log_{10} A_0 S r^2 / (r^2 + d^2).$$

Whence, (3) becomes

$$\log_{10} i_0 / T^2 = -\epsilon \phi / kT \log_{10} e + \log_{10} A_0 S r^2 / (r^2 + d^2) \quad \dots (4)$$

from which, knowing ϕ , A_0 can be calculated. If, however, ϕ be regarded as dependent on T , the slope will be equal to $\phi - T(\partial\phi/\partial T)$ and the intercept will be

$$\log_{10} A_0 \exp [-(e/k)(\partial\phi/\partial T)] \cdot S r^2 / (r^2 + d^2).$$

2. EXPERIMENTAL ARRANGEMENT.

The details of the method by which the thermionic constants of molybdenum were determined in accordance with the above ideas are briefly given below.

(a) The Molybdenum Cylinder:

A spectroscopically pure cylindrical rod was bored throughout its length so as to form a tube. This tube was provided with a tightly fitting plug of the same sample of molybdenum at each end. One of the plugs was solid, while the other, facing the Faraday Cylinder, was hollow with a wall at the end lying within the molybdenum tube (Fig. 1). There was a central hole of diameter 0.127 cm. in this

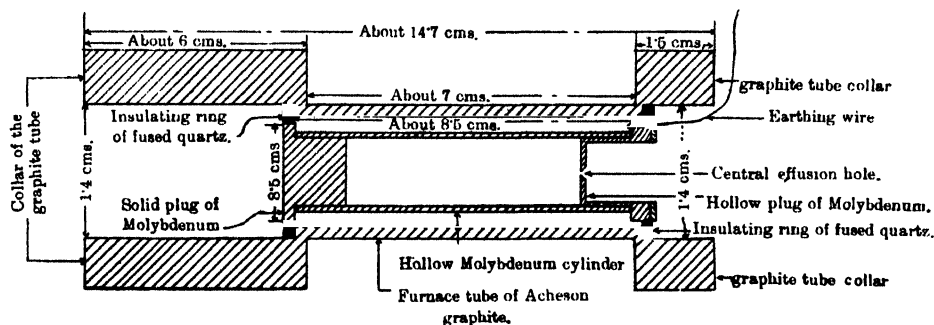


Fig. 1—Furnace tube of Acheson Graphite with hollow Cylinder of Molybdenum.

wall. It was through this hole that the electrons produced within the cavity of the molybdenum tube, when heated, effused out to be collected by the Faraday cylinder. The overall length of the molybdenum cylinder thus prepared was 8.5 cm., and the outer diameter was 8.5 mm.

The surface of the molybdenum cylinder and plugs was cleansed of all greasy matter with carbon tetrachloride after which a new emitting surface was formed by etching with dil. HCl.

This molybdenum cylinder was heated to various high temperatures in vacuum by being enclosed within, but insulated from, a graphite furnace tube which was heated by a heavy electric current from a low-tension transformer. The insulation

was accomplished by means of loosely fitting fused quartz rings on which the plugs of the molybdenum cylinder rested just outside of the furnace portion of the graphite tube. The hollow plug of molybdenum was earthed by means of a molybdenum wire.

(b) *The graphite furnace tube:*

The graphite furnace tube was made out of a cylindrical rod of Acheson graphite and had the shape shown in Fig. 1, which gives also the disposition of the molybdenum cylinder in the furnace tube. The two collars at the ends of the furnace tube acted as leads to the heating current. The diameter of the fused quartz rings was slightly larger than that of the furnace portion of the graphite tube so that they could not enter the furnace accidentally. As will be seen from the figure, the entire length of the cavity of the molybdenum cylinder as well as most of the lengths of the plugs lay within the furnace portion of the graphite tube.

(c) *The water-cooled vacuum chamber:*

Figures 2 and 3 show the vertical and horizontal sections of the vacuum chamber which housed the furnace tube and its fittings. A double walled water-

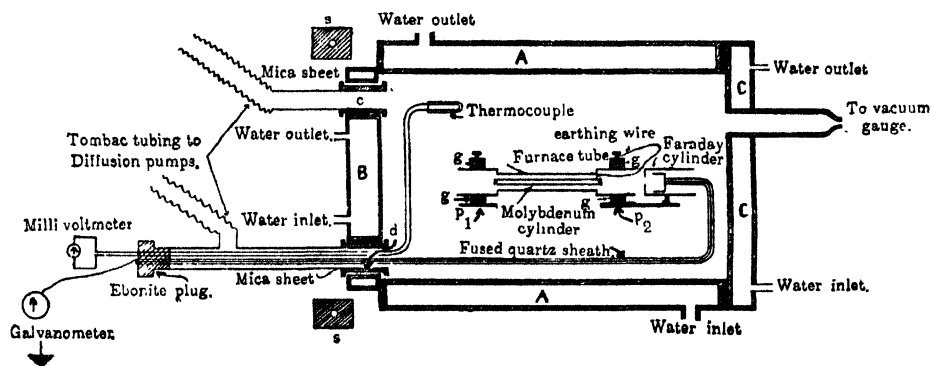


Fig. 2—Vertical section of the Water-Cooled Vacuum Furnace Chamber.

cooled cast iron drum, *A*, could be made to slide on wheels so as to make an accurate contact with a water-cooled cast iron vertical plate, *B*, fixed to the bed of an old lathe by supports, *SS*, and thus seal the contents against the atmosphere. In the beginning, a gasket of para rubber was kept between the area of contact of the edges of *A* and the plate *B*. But this practice was given up as it was found unnecessary. The vertical plate, *C*, of the drum had a tube leading to a vacuum gauge. The drum was furnished also with a side tube (Fig. 3) on which a glass window was sealed. An optical pyrometer sighted through the window enabled the temperature of the graphite furnace to be measured.

The plate, *B*, had 4 holes, *a*, *b*, *c* and *d*. The holes, *a* and *b*, each carried an annular water-cooled tube, *t*, of copper insulated from *B* by means of mica sheets. On the water-cooled ends within the chamber the tubes had exactly fitting copper collars ending in thick copper plates, *p*₁ and *p*₂, provided with slots. The upper surfaces of *p*₁ and *p*₂ made an intimate electrical contact with rectangular graphite blocks, *g*₁ between which the collars of the graphite furnace tube were clamped to *p*₁ and *p*₂. The holes, *c* and *d*, carried two brass tubes, each soldered to a length of tombac tubing leading to a 4-stage mercury diffusion pump. The brass piece in *d* had

another hole closed with an ebonite plug which carried through it the wires of a Pt-Pt 10% Rh thermocouple as well as the well-insulated copper lead from the

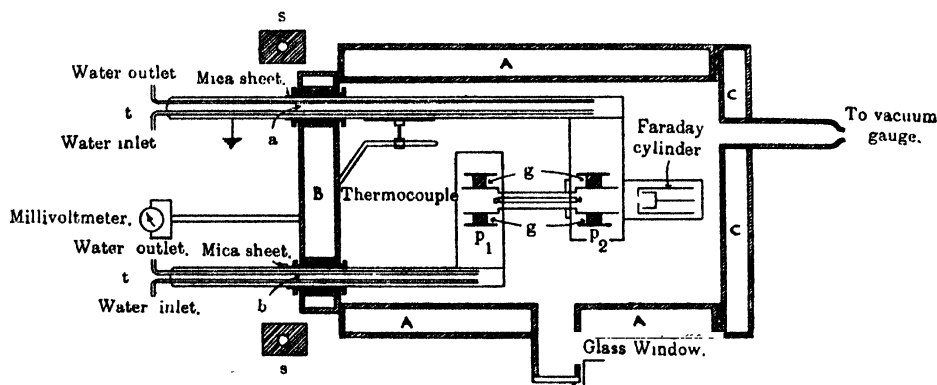


Fig. 3—Horizontal Section of the Water-Cooled Vacuum Furnace Chamber

central electrode of the Faraday cylinder. The thermocouple wires were connected to a millivoltmeter and the lead from the Faraday cylinder to a sensitive galvanometer kept outside the vacuum chamber. The electrode carrying p_2 was earthed from outside the chamber.

(d) *Temperature measurement:*

Since the molybdenum cylinder was enclosed within the graphite furnace tube, which practically formed a closed cavity, it was reasonable to suppose that the radiations within the cavity were those of a black body so that, after some time, the temperature of the interior of the molybdenum cylinder and, hence, of the emitting surface, would become the same as that of the outer surface of the graphite furnace tube. An optical pyrometer sighted from outside through the glass window in the drum *A* at the graphite furnace tube should, therefore, give the temperature also of the emitting inner surface of the molybdenum cylinder. To see if it was so, the solid plug of the molybdenum cylinder was removed and the thermojunction of the Pt-Pt 10% Rh element was inserted so as to be in contact with the centre of the molybdenum tube. The following data will show that, considering that the smallest graduation in the optical pyrometer was 5°C ., the agreement between the readings of the two instruments was satisfactory.

TABLE 1.

Temp. in $^\circ\text{C}$. of the inner surface of the molybdenum tube as measured from the thermojunction.	Temp. in $^\circ\text{C}$. of the outer surface of the graphite furnace tube as read from the optical pyrometer.
975	980
1260	1260
1440	1435
1500	1500

In the light of the above, it was considered reasonable to assume that the temperature of the inner emitting surface of the molybdenum cylinder was the same as that read on the optical pyrometer sighted at the graphite furnace tube.

It was noticed that, except at its ends where it met its collars the furnace tube glowed uniformly along its length. Readings of the optical pyrometer at different portions of the furnace confirmed the conclusion that the temperature was almost constant along the central portion of the furnace and, hence, must have been still more so within the cavity of the molybdenum cylinder.

(e) *Effect of fused quartz rings:*

Before any measurements on emission from molybdenum could be taken it was necessary to determine whether the two rings of fused quartz themselves emitted any thermionic current.

To test this the molybdenum cylinder was removed and the fused quartz rings were kept in position. No appreciable electron emission could be found even when the temperature of the furnace was kept at 1640°C . for an hour. The temperature of the fused quartz ring near the plate *B*, as measured by the thermoelement in contact with it was only 260°C . The comparatively low temperature of the ring must have been due to the fact that the temperature of the graphite furnace collar was not allowed to rise by the thick graphite blocks, *g*, in intimate contact with the water cooled thick copper plates p_1 and p_2 . To be sure that even under the experimental conditions with the molybdenum cylinder placed in position there was no spurious electronic current reaching the Faraday cylinder, the molybdenum cylinder was reversed and kept in its allotted place on the rings. The solid plug, therefore, now faced the diaphragm of the Faraday cylinder. There was, again, no appreciable electronic current reaching the Faraday cylinder.

This blank experiment established definitely that not only did the fused quartz rings produce no appreciable emission but also that no spurious electronic current was reaching the Faraday cylinder. Hence if, subsequently, on replacing the molybdenum cylinder in its proper position, any current entered the Faraday cylinder it could come only from within the molybdenum cylinder.

(f) *Degassing of the emitter:*

The contents of the vacuum chamber having been sealed by moving the drum against the plate *B*, the backing and then the two diffusion pumps were started. When the maximum possible vacuum had been created the heating current was gradually sent into the previously degassed furnace through the electrodes, *t*, connected to the transformer till the temperature rose to above 1850°C . at which it was kept constant for 2 to 3 hours. Then the temperature was decreased by steps till it fell to about 1650°C . in a few hours. This way the heating was carried on for weeks to condition the emitter and also to degass the contents of the vacuum chamber. When it was considered that the conditioning was probably complete, measurements on the thermionic emission were taken from a temperature of about 1650°C . to the lowest at which the electronic current was measurable by the galvanometer connected to the Faraday cylinder. In order to collect the saturation current positive as well as negative voltages up to 4 volts, in steps of 0.2 volts, were applied to the central electrode of the Faraday cylinder. Usually, about 1 to 2 volts, so applied, sufficed to bring about saturation electronic current. The positive thermionic currents were always negligible and were not considered. It was only when the value of the electronic work function attained a steady value that the final observations were taken.

3. OBSERVATIONS.

A typical day's observation is recorded in the following table. From the readings, taken on different days, of the galvanometer deflections for various temperatures and for different voltages on the Faraday cylinder a graph of

$\log_{10} i_0/T^2$ against $1/T$ for the various days on which the final observations were taken was plotted, i_0 being the saturation current. The numbers 1, 2, 3, 4 and 5, written against the various points on the graph in Fig. 4, indicate the number of the day on which the data were collected.

That the emission was reproducible for a given temperature is shown by the fact that, after the degassing was complete, all the values of $\log_{10} i_0/T^2$ plotted against $1/T$ for different working days fall on the same straight line.

TABLE 2.

Temp. °C.	Galvanometer		Galvanometer deflections in mms. of scale divisions when the voltage applied on the Faraday cylinder was +										Volts.
	Shunt	corresp. sensi- tivity in 10 ⁻⁹ amp./mm											
			0	0.2	0.4	0.6	0.8	1.0	2.0	3.0	4.0		
1610	1/10	17.4	20.0	34.0	49.0	62.0	68.0	72.0	72.5	73.5	74.0		
1575	1/3	5.8	20.0	47.0	82.0	110.0	120.0	127.5	128.5	130.0	131.0		
1540	1/3	5.8	10.0	24.0	42.0	56.0	67.0	73.5	74.5	76.0	77.0		
1515	1/3	5.8	2.0	12.0	25.0	37.0	48.5	49.5	50.5	51.0	52.0		
1495	1/1	1.7	20.0	58.0	95.0	108.0	119.0	119.0	119.5	120.5	121.0		
1450	1/1	1.7	7.0	22.0	37.0	55.5	55.5	56.0	57.0	58.5	60.0		
1350	1/1	1.7	2.0	6.0	8.5	9.0	9.0	9.0	10.5	11.0	12.0		

4. RESULTS.

From the slope of the straight line in Fig. 4, the value of the thermionic work function ϕ of molybdenum comes out to be 4.23 e.v.

Substituting this value of ϕ in (4), the following values of A_0 are found for the various temperatures as given below:

TABLE 3.

Temp. in °C.	..	..	..	1650	1600	1550	1500	1450	1400	1350
Value of A_0 in amp./cm. ² deg. ²	..	..	..	243	244	237	239	240	244	241

Mean 241 amp./cm.² deg.²

5. DISCUSSION.

It will be seen that the method developed in the present investigations has several distinct advantages over the usual filament type of experiments. Being dependent on the rate of effusion, which is a function only of the temperature and the value of the thermionic work function of the metal under investigation, the method is a very direct and straightforward one. There is no complication about the internal or the external reflection coefficient so that, theoretically, the method should give the value of A_0 and not that of $A_0(1-r)$ provided the temperature coefficient of ϕ is assumed to vanish. Then, since the emitting surface is completely enclosed within the graphite furnace tube, it is indirectly heated by the radiations within the graphite enclosure acting almost as a black body. Any effect of the evaporation from the surface of the metal and the consequent variation in

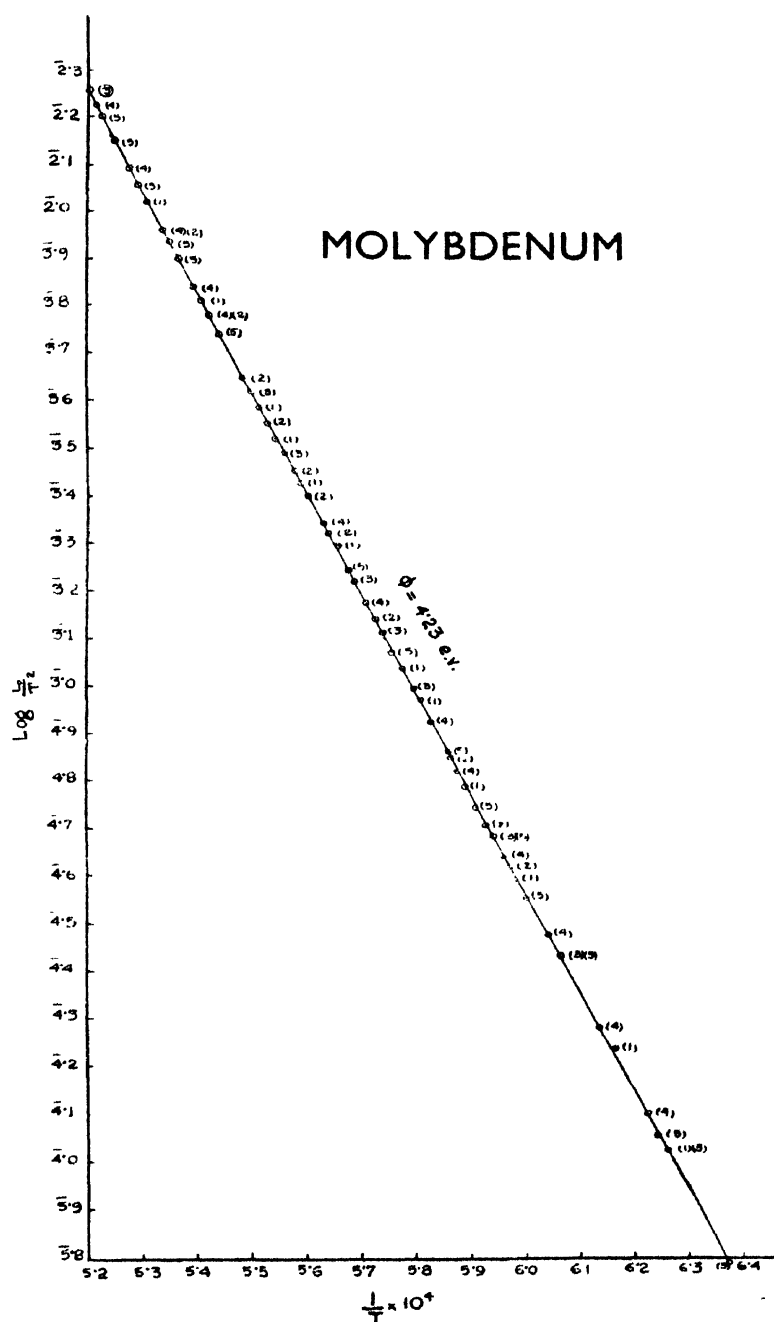


FIG. 4.

the dimensions of the sample does not affect the temperature or the emission. In other methods such a uniformity of temperature is practically impossible to attain. Since no temperature gradients are set up in the specimen no complex corrections are needed. The potential difference required to obtain saturation electronic currents from the effusion hole to the Faraday cylinder is only about 1 to 2 volts so that the difficulties about corrections for the Schottky effect do not occur here. Similarly, corrections for the lead losses, for the rise in temperature of the filament on account of the radiation received from the heated anode, and for the variation in the heating current of the filament due to the return of the space charge do not enter here.

As against the above advantages, it might be argued that the new method is liable to the following drawbacks:

Although before the introduction of the molybdenum cylinder within the graphite furnace tube the latter had been degassed, it might be said that the molecules of carbon and of its oxides, emitted during the heating of the furnace, would contaminate the emitting surface. Secondly some heat would be conducted through the molybdenum plugs and the fused quartz rings thus setting up a temperature gradient in the emitter with the consequent complications of contact potentials, etc. Lastly, although the defect is not due to any inherent fault in the method developed, but extraneous to it, the comparatively low vacuum in the present investigations may not have brought about a thorough conditioning of the emitter and may, therefore, have vitiated the results.

As regards contamination by the molecules of carbon or of its oxides, it must be remembered that the furnace was heated only after the pumps had produced the best vacuum they could. From the geometry of the apparatus it will be seen that the chance of any foreign molecule acquiring a velocity in a direction enabling it to enter the effusion hole—the only avenue possible for it to enter the molybdenum cylinder and contaminate the inner emitting surface—was very small indeed.

Similarly, the chance of any temperature gradient along the surface of the emitter being set up was small. The diameter of the fused quartz rings being larger than that of the molybdenum plugs, the area of contact between the two was small. Hence not much heat could have been lost via the non-conducting rings.

It has already been mentioned that the whole of the graphite furnace tube glowed uniformly except where it met the collars of the tube. Since the entire length of the cavity of the molybdenum cylinder as well as most of the lengths of the plugs lay within the uniformly glowing furnace tube, whatever temperature gradients occurred must have been produced at the ends of the plugs and not within the cavity of the molybdenum cylinder which formed the emitting surface.

It is difficult to estimate as to how far the results of the present investigations have suffered for a lack of the highest vacuum attainable these days. Table 4 shows the values of the thermionic constants of molybdenum obtained by different workers by other methods.

Although the data obtained by the author need not be accepted as final, it will be seen that the value of the work function obtained is in fair agreement with that obtained by other workers. The value of A_0 is not in equally good agreement. Theoretically, the new method should give the value of $A/(1-r) \approx A_0$ if the temperature coefficient of ϕ is negligible. But whether the difference is due to an insufficient degassing at high vacuum or to any natural variation in different samples of the same metal caused by the orientation of the axes of the crystals forming the emitter surface is rather difficult to say. Nichols (1940) found a difference of as much as 0.3 e.v. in the value of the work function between crystal directions (110) and (111) in a single crystal prepared of tungsten, while the value of A varied from 125 for the (112) and (001) directions to 15 for the (110) direction. Then, again, besides the above, there is what has been called a 'volume effect' caused, according to E. W. Müller, and Benjamin and Jenkins (1940), by

TABLE 4.

Thermionic Constants of Molybdenum.

Investigator	Year	Method	Value of	
			ϕ in e.v.	A in amp./cm. ² deg. ²
1. DuBridge and Roehr ..	1932	Photoelectric ..	4.15	..
		Thermionic ..	4.15	60
2. Ahearn ..	1933	Thermionic ..	4.32	..
3. Freitag and Krüger ..	1935	Thermionic ..	4.33	..
4. Krüger and Stabenow ..	1935	Cooling effect ..	4.40	..
5. Wahlin and Reynolds ..	1935	Thermionic ..	4.17	55
6. Rentschler and Henry ..	1936	Photoelectric ..	4.35	..
7. Grover ..	1937	Thermionic ..	4.2	..
8. Wright ..	1941	Thermionic ..	4.2	55 for strip and 115 for filament.
9. Mathur ..	1946	Effusion ..	4.23	241 $[.1/(1-\gamma)]$.

the periodicity of the crystal lattice which results in forbidden energy regions occurring for those electron momenta which satisfy the conditions for Bragg reflection along the various crystal directions. If such a region exists at or just above the top of the surface barrier in the case of thermionic emission, or at the top of the Fermi level in the case of field emission, some of the electrons will be absent since the energy in question will lie in the forbidden region for the corresponding directions of motion inside the crystal. We should, therefore, in the light of the above, expect to obtain a sort of an average value for the thermionic constants which may vary from sample to sample depending on the disposition of the axes of the crystals forming the emitting surface. It will be seen that the values of ϕ obtained by different workers using the most up-to-date vacuum technique vary by as much as 0.25 volt for molybdenum, while the value of A varies between 55 and 115. It is possible that in the case of the present investigations a long process of high temperature treatment at moderately high vacuum may have sufficed to force the foreign molecules to quit the surface and to condition it so that the investigations of the author may not, after all, have suffered materially for lack of a very high vacuum. As Wohlfarth (1948) says, until the various disturbing effects are more fully understood, no really satisfactory comparison of theoretical and experimental results can be made.

The author wishes to thank Sir K. S. Krishnan, F.R.S., for kindly suggesting the problem and for his guidance, and Dr. B. N. Srivastava for much help. The investigation was carried out during 1945-46 in the Physics Department of the Allahabad University where the author had gone on study leave from the Lucknow University. For part of the time, the author was appointed as a research assistant to Professor Krishnan by the Council of Scientific and Industrial Research, New Delhi.

SUMMARY.

By measuring the electronic current effusing out of a small hole in an otherwise closed cylinder of molybdenum, heated to various high temperatures in a graphite furnace tube worked in vacuum, the electronic work function of molybdenum was found to be 4.23 e.v. in good agreement with some of the recent determinations by other methods. The value of the constant A , which was not in similar good agreement with the values found by other investigators, was found to be 241 amp./cm.² deg.²

The merits of this newly developed method are discussed.

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THE THERMIONIC WORK FUNCTION OF IRON—II

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INTRODUCTION.

In an earlier paper (Mathur, 1953), details have been given of a new method of determining the thermionic constants of molybdenum by measuring the electronic current effusing out of a small hole in an otherwise closed cylinder of the metal heated to various high temperatures in vacuum by being enclosed within a cylindrical graphite furnace tube through which heavy electric currents could be sent from a transformer. The present paper gives the results on iron investigated in the same way.

Iron is of some interest as it changes from the α -form to the β -form at 769°C. , to γ -form at 906°C. , and to δ -form at 1404°C. Since the measurements were made in the temperature range $1370^{\circ}\text{--}1490^{\circ}\text{C.}$, the effect of transition between the γ and the δ -forms alone could be investigated.

PREPARATION OF THE EMITTING SURFACE.

A cylindrical tube, with a tightly fitting plug at each end, was made out of an ordinary piece of iron in the laboratory. One of the plugs was solid, while the other was hollow except for a thin wall at the end which had a central hole of diameter 0.751 mm. The overall length of the iron cylinder, when fitted with the plugs, was 8.5 cms. and the outer diameter was 0.8 cms.

On the inner walls of the cylinder and the plugs a coating of iron was deposited by electrolysis from a solution of Ferrous chloride. The prepared surface was then cleansed of all greasy and other organic matter by chromic acid and washing. This was followed by a slight etching of the surface with dilute HCl washed away with hot distilled water. The iron cylinder was then dried and carefully placed on fused quartz rings within the previously de-gassed graphite furnace tube and the vacuum furnace chamber assembled as already described in the paper on molybdenum.

The de-gassing of the iron cylinder was a problem. Although iron melts at 1530°C. , it softens at a much lower temperature. Hence there was always a risk of the iron cylinder sagging and short-circuiting the graphite furnace tube. A heavy electric current would then flow through the iron cylinder and melt it. This would not only ruin the graphite furnace but also the surface of the copper plate electrodes and make them unfit for further use. This behaviour of the iron may be due to the rearrangement of crystal planes on its surface on passing from the β - to the γ -form. H. B. Wahlin (1942) also remarks that 'each time the filament passed through the A_3 point, it warped and with repeated transitions twisted sufficiently to short circuit portions of the specimen'. In the light of the above experience, it was decided to do the major part of the de-gassing of the iron cylinder at temperatures lower than about 850°C. and to de-gas at higher temperatures only for very short durations until the value of the thermionic work function attained a steady value. It thus took several weeks to prepare the specimen for the final sets of observations.

When the iron cylinder was considered to be conditioned, the usual practice was to raise the temperature to about 750°C . in about an hour. The temperature was then raised to about 1500°C . and the readings of the thermionic emission were quickly taken with decreasing temperatures till about 1350°C . was reached when no appreciable current could be detected by a galvanometer connected to the Faraday cylinder which collected the effusion current. The furnace was then slowly lowered in temperature and the heating current finally switched off.

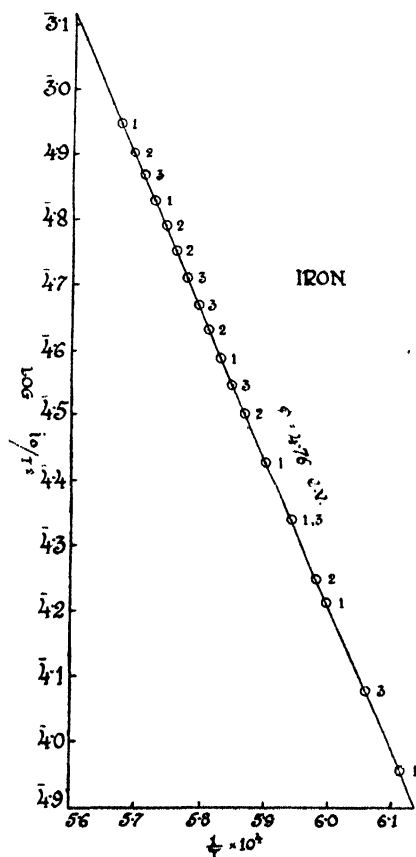
CALCULATIONS.

In the paper on molybdenum the following equation has been developed:

$$\log_{10} \frac{i_0}{T^2} = -\frac{\phi}{kT} \log_{10} e + \log_{10} A_0 \frac{Sr^2}{r^2 + d^2}$$

where i_0 is the saturation electronic current collected by the Faraday cylinder with a diaphragm of radius r ; T is the absolute temperature of the emitting surface; ϕ is the work function; A_0 is the constant in Richardson's T^2 equation of thermionic emission; S is the area of the effusion hole; d is the distance between the effusion hole and the diaphragm of the Faraday cylinder; and K is the well-known Boltzmann constant.

Hence, if a graph of $\log_{10} i_0/T^2$ is plotted against the corresponding values of $1/T$, the value of the work function ϕ can be found from the slope of the curve,



while knowing ϕ , r , d , and the radius of the effusion hole the value of the constant A_0 can be determined.

RESULTS.

The figure alongside gives the values of $\log_{10} i_0/T^2$ against the corresponding values of $1/T$ obtained from observations taken on three different days as indicated by the numbers given near the various points on the line. The value of the thermionic work function, as determined from the slope of the line, comes out to be 4.76 e.v.

Taking the above value of ϕ , and $r = 0.426$ cms., $d = 1.3$ cms., and the radius of the effusion hole $= 0.0751$ cms., the average for different temperatures of the value of A_0 was found to be 705 amp./cm.² deg.²

It will be seen that since a straight line fits through the observations no particular change occurred in the value of the work function on account of transitions between the γ - and the δ -forms.

The following table gives the values of the thermionic constants of iron as found by different investigators. (Jentzch, 1908; Hamer, 1922; Roy, 1926; Welch, 1928; Cardwell, 1928; Siljeholm, 1931; Glasoe, 1931; Distler and Monch, 1933; Wahlin, 1942; Mathur, 1953).

Investigators.	Year.	Method.	ϕ in e.v.	A_0 in amp./cm. deg.
1. Jentzch ..	1908	Thermionic ..	4.04	..
2. Hamer ..	1924	Photoelectric ..	4.71	..
3. Roy ..	1926	.. ..	4.2	..
4. Welch ..	1928	.. ..	3.92	..
5. Cardwell ..	1928	.. ..	4.72 (γ -iron)	..
6. Siljeholm ..	1931	Thermionic ..	4.77 (γ -iron)	..
7. Glasoe ..	1931	Photoelectric & contact potential ..	4.77	..
8. Distler and Monch	1933	Thermionic ..	4.04	..
9. Wahlin ..	1942	.. ..	4.48 (below β - γ transition). 4.21 (above β - γ transition)	26
10. Mathur ..	1953	Effusion ..	4.76 (δ & γ -iron)	1.5 705

ACKNOWLEDGEMENTS.

The author thanks Sir K. S. Krishnan for his guidance and encouragement, Dr. B. N. Srivastava for advice and help, the authorities of the Allahabad University for the facilities of the Physics Department in which this work was carried out during 1945-46, and, finally, the Council of Scientific and Industrial Research, India, for the appointment of the author as a research assistant to Prof. Krishnan.

SUMMARY.

From the rate of effusion of electrons from a small hole in an otherwise closed cylinder of iron heated in vacuum to different high temperatures the thermionic work function of iron was found to be 4.76 e.v., while the value of the constant A_0 was found to be 705 amp./cm.² deg.² between 1370° C. and 1490° C.

No particular effect of transition from the δ - to the γ -form of iron was noticeable. This was probably due to the comparatively quick changes in temperature during the investigations which did not allow any form of iron to become stable.

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THE THERMIONIC WORK FUNCTION OF GRAPHITE—III

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(Communicated by Dr. B. N. Srivastava, F.N.I.)

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INTRODUCTION.

A. S. Bhatnagar (1944) determined the value of the electron work function of graphite by heating a cylinder of graphite closed on all sides except for a small hole at one end to different high temperatures in vacuum and measuring the rate of flow of electrons effusing out of the hole by means of a galvanometer attached to a Faraday Cylinder which collected the electrons.

The work under report is an extension of the investigations of the thermionic constants of molybdenum (Mathur, 1953) and of iron (Mathur, 1953). In principle the method is the same as that of Bhatnagar, but in the matter of design, it is an improvement on the latter's work, as the cylinder of graphite with the effusion hole at one end was heated by being enclosed in an outer furnace tube of graphite and not by an electric current flowing directly through the experimental tube, as in Bhatnagar's experiment. This enabled the graphite cylinder under investigation to acquire a much more uniform temperature than could have been possible by direct electrical heating. All the details of the experiment were the same as those on molybdenum (Mathur, 1953).

RESULTS.

From the readings of the electron effusion current at different temperatures, the values of $\log_{10} i_0/T^2$ were calculated and plotted against the corresponding values of $1/T$ as shown in the accompanying figure. The numbers 1, 2, . . . 5, indicated against the various points on the graph show the number of the day on which the data were collected. It will be seen that the same straight line fits all the points showing that the data were reproducible.

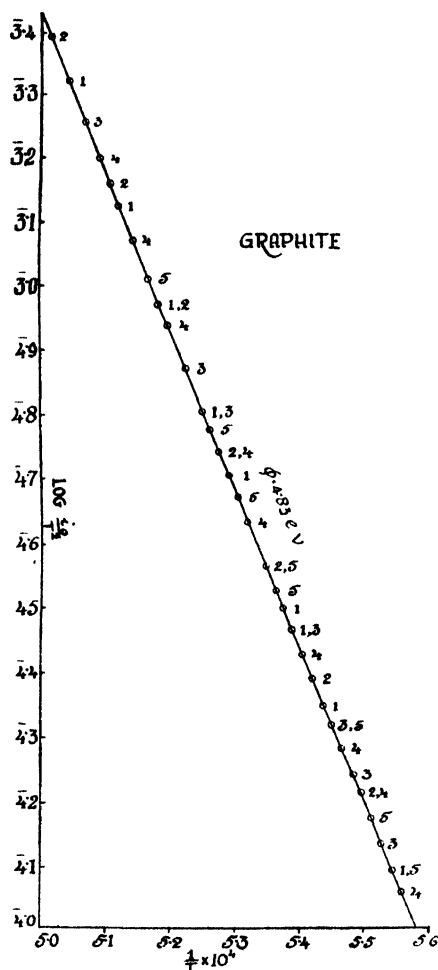
From the slope of the line in the figure, the value of the electron work function of graphite comes out to be 4.83 e.v.

Substituting the above value of the work function in the equation (Mathur, 1953)

$$\log_{10} \frac{i_0}{T^2} = -\frac{\phi}{kT} \log_{10} e + \log_{10} A_0 \frac{Sr^2}{r^2 + d^2},$$

and taking r , the radius of the diaphragm of the Faraday cylinder to be 0.426 cms., d , the distance between the diaphragm and the effusion hole to be 1.3 cms., and the radius of the effusion hole to be 0.0502 cms., the average of the various values of the constant A_0 was found to be 170 amp./cm.² deg.²

The following table summarises the thermionic data obtained by the more recent workers (Roy, 1926; Reiman, 1938; Bhatnagar, 1944; Braun and Busch, 1947; Mathur, 1953) on graphite. The values obtained in the present investigations also are given.



Investigators.	Year.	Method.	Work function in e.v.	A in amp./cm. ² deg. ²
1. Roy ..	1926	Photoelectric ..	4.82	..
2. Reiman ..	1938	Thermionic ..	4.84	30
3. Bhatnagar ..	1944	Effusion ..	4.84	..
4. Braun and Busch ..	1947	Thermionic ..	4.39	15
5. Mathur ..	1953	Effusion ..	4.83	170

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SUMMARY.

From the rate of effusion of electrons through a small hole in an otherwise closed cylinder of graphite indirectly heated in vacuum to various high temperatures, the thermionic constants of graphite have been determined. This investigation is a continuation of the method adopted by the author for work on molybdenum and iron. The value of the electron work function for graphite was found to be 4.83 e.v. and that of the constant A_0 was 170 amp./cm.² deg.²

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INVERSION FORMULAE FOR A GENERALIZED LAPLACE INTEGRAL

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(Communicated by Dr. R. S. Varma, F.N.I.)

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Dr. R. S. Varma (1952) has recently given a generalization of the Laplace Integral

$$f(s) = \int_0^{\infty} e^{-st} d\alpha(t) \quad \dots \quad \dots \quad (1.1)$$

in the form

$$f(s) = \int_0^{\infty} (st)^{m-\frac{1}{2}} e^{-\frac{1}{2}st} W_{k,m}(st) d\alpha(t) \quad \dots \quad \dots \quad (1.2)$$

where $\alpha(t)$ is a function of bounded variation in $0 < t \leq R$ for every R and $R(m) > 0$.

If we put $k+m = \frac{1}{2}$, the integral (1.2) reduces to (1.1) as

$$(st)^{m-\frac{1}{2}} e^{-\frac{1}{2}st} W_{\frac{1}{2}-m,m}(st) \equiv e^{-st}.$$

If $\alpha(t)$ be absolutely continuous and $d\alpha(t) = \phi(t) dt$, then

$$f(s) = \int_0^{\infty} (st)^{m-\frac{1}{2}} e^{-\frac{1}{2}st} W_{k,m}(st) \phi(t) dt. \quad \dots \quad \dots \quad (1.3)$$

In this paper I have worked out a few inversion formulae for the generalized Laplace transform (1.3). The variable s has been assumed to be real.

2. First Inversion Formula.

Multiplying both the sides of

$$f(s) = \int_0^{\infty} (st)^{m-\frac{1}{2}} e^{-\frac{1}{2}st} W_{k,m}(st) \phi(t) dt$$

by s^{-l} and integrating from 0 to ∞ we have

$$\int_0^{\infty} s^{-l} f(s) ds = \int_0^{\infty} \int_0^{\infty} s^{m-l-\frac{1}{2}} t^{m-\frac{1}{2}} e^{-\frac{1}{2}st} W_{k,m}(st) \phi(t) dt ds.$$

Let

$$\left. \begin{aligned} \phi(t) &= O(t^p) \text{ for small } t, \\ &= O(e^{-t^p}) \text{ for large } t. \end{aligned} \right\}, R(p) > 0. \quad \dots \quad \therefore (2.1)$$

Then if

$$A(s) = s^{m-l-\frac{1}{2}} \int_0^\epsilon t^{m-\frac{1}{2}} e^{-\frac{1}{2}st} W_{k,m}(st) \phi(t) dt \quad \text{where } \epsilon \text{ is small,}$$

and

$$B(t) = t^{m-\frac{1}{2}} \phi(t) \int_0^\infty s^{m-l-\frac{1}{2}} e^{-\frac{1}{2}st} W_{k,m}(st) ds$$

we see that $A(s)$ is uniformly convergent in $s > 0$ provided that

$$R(m-l \pm m) > 0, \quad R(m \pm m + \rho + 1) > 0,$$

and $B(t)$ is uniformly convergent in $t > 0$ provided that

$$R(m \pm m + \rho) > 0, \quad R(m-l \pm m + 1) > 0,$$

as (Whittaker and Watson, 1946, p. 346)

$$W_{k,m}(x) = O(x^{\pm m + \frac{1}{2}}) \text{ for small } x.$$

Also if we consider the integral

$$\int_T^\infty t^{m-\frac{1}{2}} \phi(t) dt \int_{T'}^\infty s^{m-l-\frac{1}{2}} e^{-\frac{1}{2}st} W_{k,m}(st) ds$$

where T and T' are large we find on account of the values (2.1) of $\phi(t)$ and the estimate (Whittaker and Watson, 1946, p. 343)

$$W_{k,m}(x) = O(x^{\frac{1}{2}} e^{-\frac{1}{2}x}) \text{ where } x \text{ is large,} \quad \dots \quad (2.2)$$

of $W_{k,m}(x)$, that the integral does not exceed a constant multiple of

$$\int_T^\infty |t^{h+m-\frac{1}{2}} e^{-t^p}| dt \int_{T'}^\infty |s^{h+m-l-\frac{1}{2}} e^{-st}| ds$$

which tends to zero provided that $R(\nu) > 0$.

Hence the order of integration can be changed if the conditions

$$R(m-l \pm m) > 0, \quad R(m \pm m + \rho) > 0, \quad R(\nu) > 0,$$

which, by the principle of analytic continuation, can be waived to

$$R(m-l \pm m + 1) > 0, \quad R(m \pm m + \rho + 1) > 0, \quad R(\nu) > 0, \quad \dots \quad (2.3)$$

are satisfied.

Therefore changing the order of integration we have

$$\int_0^\infty s^{-l} f(s) ds = \int_0^\infty t^{m-\frac{1}{2}} \phi(t) dt \int_0^\infty s^{m-l-\frac{1}{2}} e^{-\frac{1}{2}st} W_{k,m}(st) ds$$

provided conditions (2.3) are satisfied.

If we now apply Goldstein's formula (1932)

$$\int_0^\infty x^{l_1-1} e^{-(\alpha^2+\frac{1}{2})x} W_{k_1, m_1}(x) dx = \frac{\Gamma(l_1+m_1+\frac{1}{2}) \Gamma(l_1-m_1+\frac{1}{2})}{\Gamma(l_1-k_1+1)} \\ \times {}_2F_1[l_1+m_1+\frac{1}{2}, l_1-m_1+\frac{1}{2}; l_1-k_1+1; -\alpha^2] \quad \dots \quad (2.4)$$

where

$$R(l_1 \pm m_1 + \frac{1}{2}) > 0, \quad R(\alpha^2 + 1) > 0,$$

we get

$$\int_0^\infty s^{-l} f(s) ds = \frac{\Gamma(2m-l+1) \Gamma(1-l)}{\Gamma(m-k-l+\frac{3}{2})} \int_0^\infty t^{l-1} \phi(t) dt$$

where

$$R(2m-l+1) > 0, \quad R(1-l) > 0.$$

Applying Mellin's inversion formula (Titchmarsh, 1937, p. 46) to the integral on the right we have

$$\frac{1}{2} \{ \phi(t+0) + \phi(t-0) \} = \frac{1}{2\pi i} \text{Lt}_{\tau \rightarrow \infty} \int_{c-i\tau}^{c+i\tau} \frac{\Gamma(m-k-l+\frac{3}{2})}{\Gamma(2m-l+1) \Gamma(1-l)} t^{-l} \psi(l) dl$$

where

$$\psi(l) = \int_0^\infty s^{-l} f(s) ds$$

provided that

(i) the integral $\int_0^\infty x^{c-1} \phi(x) dx$ converges absolutely,

(ii) the integral $\int_0^\infty x^{-l} f(x) dx$ also converges absolutely ($l = c + i\tau$, $-\infty < \tau < \infty$)

and

(iii) $\phi(x)$ is of bounded variation in the neighbourhood of the point $x = t$ ($t > 0$).

If we put $k = \frac{1}{2} - m$, we have

$$\frac{1}{2} \{ \phi(t+0) + \phi(t-0) \} = \frac{1}{2\pi i} \text{Lt}_{\tau \rightarrow \infty} \int_{c-i\tau}^{c+i\tau} \frac{t^{-l}}{\Gamma(1-l)} \int_0^\infty s^{-l} f(s) ds dl$$

which is the corresponding result in the theory of ordinary Laplace transform (Titchmarsh, 1937, p. 316).

3. Second Inversion Formula.

Let $F(s)$ be a continuous function of s in $(0, \infty)$ such that its derivatives up to the n -th order are all continuous in $(0, \infty)$ and

$$\frac{d^n}{ds^n} [F(s)] = f(s) = \int_0^\infty (st)^{m-\frac{1}{2}} e^{-\frac{1}{2}st} W_{k, m}(st) \phi(t) dt.$$

Then if we integrate (1.3) with respect to s , n times we have

$$F(s) = (-)^n \int_0^\infty t^{-n} (st)^{m+\frac{1}{2}(n-1)} e^{-\frac{1}{2}st} W_{h-\frac{1}{2}n, m+\frac{1}{2}n}(st) \phi(t) dt$$

as

$$\int (st)^{m-\frac{1}{2}} e^{-\frac{1}{2}st} W_{h, m}(st) ds = -t^{-1} (st)^m e^{-\frac{1}{2}st} W_{h-\frac{1}{2}, m+\frac{1}{2}}(st). \quad \dots (3.1)$$

Multiplying both sides by

$${}_{n+1}F_{2n+1} \left[\begin{matrix} \alpha_1, \alpha_2, \dots, \alpha_{n+1}, \\ \beta_1, \beta_2, \dots, \beta_{n+1}, \gamma_1, \gamma_2, \dots, \gamma_n \end{matrix} ; -p \left(\frac{s}{n+1} \right)^{n+1} \right]$$

and integrating with respect to s from 0 to ∞ , we have

$$\begin{aligned} & \int_0^\infty F(s) {}_{n+1}F_{2n+1} \left[\begin{matrix} \alpha_1, \alpha_2, \dots, \alpha_{n+1}, \\ \beta_1, \beta_2, \dots, \beta_{n+1}, \gamma_1, \gamma_2, \dots, \gamma_n \end{matrix} ; -p \left(\frac{s}{n+1} \right)^{n+1} \right] ds \\ &= (-)^n \int_0^\infty \int_0^\infty {}_{n+1}F_{2n+1} \left[\begin{matrix} \alpha_1, \alpha_2, \dots, \alpha_{n+1}, \\ \beta_1, \beta_2, \dots, \beta_{n+1}, \gamma_1, \gamma_2, \dots, \gamma_n \end{matrix} ; -p \left(\frac{s}{n+1} \right)^{n+1} \right] \\ & \quad \times t^{-n} (st)^{m+\frac{1}{2}(n-1)} e^{-\frac{1}{2}st} W_{h-\frac{1}{2}n, m+\frac{1}{2}n}(st) \phi(t) dt ds \\ &= (-)^n \int_0^\infty t^{-n-1} \phi(t) dt \int_0^\infty v^{\{m+\frac{1}{2}(n+1)\}-1} e^{-\frac{1}{2}v} W_{h-\frac{n}{2}, m+\frac{n}{2}}(v) \\ & \quad \times {}_{n+1}F_{2n+1} \left[\begin{matrix} \alpha_1, \alpha_2, \dots, \alpha_{n+1}, \\ \beta_1, \beta_2, \dots, \beta_{n+1}, \gamma_1, \gamma_2, \dots, \gamma_n \end{matrix} ; -\frac{p}{\{(n+1)t\}^{n+1}} t^{n+1} \right] dv \quad (3.2) \end{aligned}$$

on changing the order of integration in the right-hand integral and making a slight change of variable, provided that

$$R\left(m \pm m + \frac{n}{2} \pm \frac{n}{2} + 1\right) > 0, \quad R\left(m \pm m - \frac{n}{2} \pm \frac{n}{2} + \rho + 1\right) > 0, \quad R(\nu) > 0.$$

Evaluating the v -integral with the help of the following result due to Pasricha (1943)

$$\begin{aligned} & \int_0^\infty x^{\mu-1} e^{-(\alpha^2+\frac{1}{2})x} W_{h, \nu}(x) {}_rF_s \left(\begin{matrix} l_1, l_2, \dots, l_r \\ m_1, m_2, \dots, m_s \end{matrix} ; y, x^p \right) dx \\ &= \sum_{m=0}^\infty \frac{(l_1)_m (l_2)_m \dots (l_r)_m \Gamma(a+pm) \Gamma(b+pm)}{(m_1)_m (m_2)_m \dots (m_s)_m \Gamma(c+pm)} \\ & \quad \times {}_2F_1(a+pm, b+pm; c+pm; -\alpha^2) \quad \dots (3.3) \end{aligned}$$

where

$$a = \mu + \nu + \frac{1}{2}, \quad b = \mu - \nu + \frac{1}{2}, \quad c = \mu - k + 1$$

and

$$R(a) > 0, \quad R(b) > 0, \quad p < s + 1 - r, \quad R(\alpha^2 + 1) > 0$$

we get

$$I = (-)^n \int_0^\infty t^{-n-1} J \phi(t) dt \quad \dots \quad (3.4)$$

where

$$I = \int_0^\infty F(s) {}_{n+1}F_{2n+1} \left[\begin{matrix} \alpha_1, \alpha_2, \dots, \alpha_{n+1}, \\ \beta_1, \beta_2, \dots, \beta_{n+1}, \gamma_1, \gamma_2, \dots, \gamma_n \end{matrix} ; -p \left(\frac{s}{n+1} \right)^{n+1} \right] ds$$

and

$$J = \sum_{r=0}^{\infty} \frac{(\alpha_1)_r \dots (\alpha_{n+1})_r \Gamma(a+n+1-r) \Gamma(b+n+1-r)}{(\beta_1)_r \dots (\beta_{n+1})_r (\gamma_1)_r \dots (\gamma_n)_r \Gamma(c+n+1-r)} \left\{ -\frac{p}{\{(n+1)t\}^{n+1}} \right\}^r$$

a being equal to $2m+n+1$, $b=1$, $c=m-k+n+\frac{3}{2}$.

Putting

$$\left. \begin{aligned} \alpha_i &= \frac{c+i-1}{n+1}, \beta_i = \frac{a+i-1}{n+1} \quad (i=1, 2, \dots, n+1) \\ \gamma_j &= \frac{b+j-1}{n+1} \quad (j=1, 2, \dots, n) \end{aligned} \right\} \quad \dots \quad (3.5)$$

and using the multiplication formula (Gupta, 1948).

$$\Gamma(a+nr) = n^r \Gamma(a) \left(\frac{a}{n} \right)_r \left(\frac{a+1}{n} \right)_r \dots \left(\frac{a+n-1}{n} \right)_r \quad \dots \quad (3.6)$$

the above result gives

$$H = (-)^n \frac{\Gamma(2m+n+1)}{\Gamma(m-k+n+\frac{3}{2})} \int_0^\infty t^{-n-1} {}_1F_0 \left(1; -\frac{p}{t^{n+1}} \right) \phi(t) dt$$

where H is the value of I with the parameters α 's, β 's and γ 's having values given by (3.5).

We therefore have

$$\int_0^\infty \frac{\beta(u) du}{p+u} = \psi(p) = (-)^n \frac{\Gamma(m-k+n+\frac{3}{2})}{\Gamma(2m+n+1)} H \quad \dots \quad (3.7)$$

where

$$\beta(t) = \frac{\phi(t^{1/(n+1)})}{(n+1) t^{n/(n+1)}}$$

and $\phi(t)$ is such that the integral on the left converges.

The left-hand side is the ordinary Stieltjes transform.

If we now define an operator $L_{l,u} [\psi(x)]$ for any real positive number u by the equations

$$\left. \begin{aligned} L_{0,u} [\psi(x)] &= \psi(u) \\ L_{1,u} [\psi(x)] &= \frac{d}{du} [u \psi(u)] \\ L_{l,u} [\psi(x)] &= \frac{(-u)^{l-1}}{[l]_{-2}} \cdot \frac{d^{2l-1}}{du^{2l-1}} [u^l \psi(u)] \end{aligned} \right\} \quad \dots \quad (3.8)$$

($l=2, 3, \dots$)

and $\psi(u)$ possesses derivatives of all orders less than $2l$, then, by a result of Widder (1941, p. 345), we get

$$\beta(u) = \lim_{t \rightarrow \infty} \{L_{l,u}[\psi(p)]\}$$

for almost all positive u .

Hence

$$\phi(t) = (n+1)t^n \left\{ \lim_{t \rightarrow \infty} [L_{l,u}[\psi(p)]] \right\}_{u=t^{n+1}}$$

for almost all positive t .

It remains to justify the change in the order of integration in (3.2). To do so let us put

$$\begin{aligned} \delta(t) &= t^{m-\frac{n}{2}-\frac{1}{2}} \phi(t) \int_0^\epsilon s^{m+\frac{n}{2}-\frac{1}{2}} e^{-\frac{1}{2}st} W_{k-\frac{1}{2}n, m+\frac{1}{2}n}(st) \\ &\quad \times {}_{n+1}F_{2n+1} \left[\begin{matrix} \alpha_1, \alpha_2, \dots, \alpha_{n+1}, \\ \beta_1, \beta_2, \dots, \beta_{n+1}, \gamma_1, \gamma_2, \dots, \gamma_n \end{matrix}; -p \left(\frac{s}{n+1} \right)^{n+1} \right] ds \end{aligned}$$

where ϵ is small,

$$\begin{aligned} \chi(s) &= s^{m+\frac{n}{2}-\frac{1}{2}} {}_{n+1}F_{2n+1} \left[\begin{matrix} \alpha_1, \alpha_2, \dots, \alpha_{n+1}, \\ \beta_1, \beta_2, \dots, \beta_{n+1}, \gamma_1, \gamma_2, \dots, \gamma_n \end{matrix}; -p \left(\frac{s}{n+1} \right)^{n+1} \right] \\ &\quad \times \int_0^\infty t^{m-\frac{n}{2}-\frac{1}{2}} e^{-\frac{1}{2}st} W_{k-\frac{1}{2}n, m+\frac{1}{2}n}(st) \phi(t) dt \end{aligned}$$

and let the behaviour of $\phi(t)$ be given by (2.1).

Then $\delta(t)$ is uniformly convergent in $t \geq 0$ provided that

$$R\left(m \pm m - \frac{n}{2} \pm \frac{n}{2} + \rho\right) \geq 0, \quad R\left(m \pm m + \frac{n}{2} \pm \frac{n}{2} + 1\right) > 0$$

and $\chi(s)$ is uniformly convergent in $s \geq 0$ provided that

$$R\left(m \pm m + \frac{n}{2} \pm \frac{n}{2}\right) \geq 0, \quad R\left(m \pm m - \frac{n}{2} \pm \frac{n}{2} + \rho + 1\right) > 0.$$

Again if we consider the integral

$$\begin{aligned} I_1 &= \int_T^\infty t^{m-\frac{n}{2}-\frac{1}{2}} \phi(t) dt \int_{T'}^\infty s^{m+\frac{n}{2}-\frac{1}{2}} e^{-\frac{1}{2}st} W_{k-\frac{1}{2}n, m+\frac{1}{2}n}(st) \\ &\quad \times {}_{n+1}F_{2n+1} \left[\begin{matrix} \alpha_1, \alpha_2, \dots, \alpha_{n+1}, \\ \beta_1, \beta_2, \dots, \beta_{n+1}, \gamma_1, \gamma_2, \dots, \gamma_n \end{matrix}; -p \left(\frac{s}{n+1} \right)^{n+1} \right] ds \end{aligned}$$

where T and T' are large, we find, on account of the estimates (2.1) and on account of the following behaviour of ${}_{n+1}F_{2n+1}$ (Gupta, 1948).

$$\begin{aligned} &{}_{n+1}F_{2n+1} \left[\begin{matrix} \alpha_1, \alpha_2, \dots, \alpha_{n+1}, \\ \beta_1, \beta_2, \dots, \beta_{n+1}, \gamma_1, \gamma_2, \dots, \gamma_n \end{matrix}; -p \left(\frac{s}{n+1} \right)^{n+1} \right] \\ &\sim \left(p^{\frac{1}{n+1}} s \right)^{\theta'} \exp \left\{ \left(p^{\frac{1}{n+1}} s \right) e^{\frac{\pi i}{n+1}} \right\} + \sum_{r=1}^{n+1} a_n \left(s p^{\frac{1}{n+1}} \right)^{-(n+1)\alpha_r} \quad (s \rightarrow \infty) \end{aligned}$$

where

$$\theta' = \Sigma \alpha_n - \Sigma \beta_n - \Sigma \gamma_n + \frac{n}{2},$$

that I_1 does not exceed a constant multiple of

$$\int_T^\infty |t^{m-n+k-\frac{1}{2}} e^{-t^p}| dt \int_{T'}^\infty |s^{m+k-\frac{1}{2}} \left\{ s^{\theta'} e^{sp \frac{1}{n+1}} e^{\frac{\pi i}{n+1}} + \sum_{r=1}^{n+1} s^{-(n+1)\alpha_r} \right\} e^{-st} | ds$$

which tends to zero for a given p provided that $R(\nu) > 0$.

Hence the change in the order of integration is justified under the conditions

$$R\left(m \pm m + \frac{n}{2} \pm \frac{n}{2}\right) > 0, \quad R\left(m \pm m - \frac{n}{2} \pm \frac{n}{2} + \rho\right) > 0, \quad R(\nu) > 0,$$

which can be relaxed to

$$R\left(m \pm m + \frac{n}{2} \pm \frac{n}{2} + 1\right) > 0, \quad R\left(m \pm m - \frac{n}{2} \pm \frac{n}{2} + \rho + 1\right) > 0, \quad R(\nu) > 0,$$

by the principle of analytic continuation.

4. Third Inversion Formula :

Here we shall assume k and m to be both real.

Let us define differential operators U , V_q by

$$\left. \begin{aligned} U_0[f(s)] &= f(s) \\ U_1[f(s)] &= (-1)s^{m-k-\frac{3}{2}} D[s^{k-m+\frac{1}{2}} f(s)] \\ U_q[f(s)] &= (-1)^q s^{m-k-q-\frac{1}{2}} D^q[s^{k-m+\frac{1}{2}} f(s)] \\ &\quad (q = 2, 3, \dots) \end{aligned} \right\} \dots \dots (4.1)$$

where

$$D \equiv s^2 \frac{d}{ds}$$

and

$$V_q[f(u)] = \frac{u^{-1}}{\Gamma(q+k+m-\frac{1}{2})} \left[U_q \{ f(s) \} \right]_{s=\frac{q+k+m-\frac{1}{2}}{u}}$$

Since (Sharma, 1939)

$$\frac{d}{dx} \left[x^k e^{-\frac{1}{2}x} W_{k,m}(x) \right] = -x^{k-1} e^{-\frac{1}{2}x} W_{k+1,m}(x)$$

applying the operator U to $g(s) \equiv (st)^{m-\frac{1}{2}} e^{-\frac{1}{2}st} W_{k,m}(st)$,

we find that $U_q[g(s)] = (st)^{m-\frac{1}{2}} e^{-\frac{1}{2}st} W_{k+q,m}(st)$.

If (1.3) converges, we can evaluate the derivatives of $f(s)$ by differentiation under the integral sign.

Therefore

$$U_q[f(s)] = \int_0^\infty (st)^{m-\frac{1}{2}} e^{-\frac{1}{2}st} W_{k+q,m}(st) \phi(t) dt.$$

If the variable t be changed to v by the relation $t = uv$, we have

$$U_q[f(s)] = u \int_0^\infty (su)^{m-\frac{1}{2}} e^{-\frac{1}{2}su} W_{k+q, m}(su) \phi(uv) dv.$$

Putting $su = l$, the right-hand side becomes

$$\frac{l}{s} \int_0^\infty (lv)^{m-\frac{1}{2}} e^{-\frac{1}{2}lv} W_{k+q, m}(lv) \phi(uv) dv.$$

Therefore substituting the asymptotic estimate (2.2) of $W_{k+q, m}(lv)$ in the integral we have

$$\text{Lt}_{l \rightarrow \infty} \left[\frac{s U_q \{f(s)\}}{l} \right] = \text{Lt}_{l \rightarrow \infty} \frac{l}{s} \int_0^\infty (lv)^{k+q+m-\frac{1}{2}} e^{-lv} \phi(uv) dv$$

If we take $l = k+q+m-\frac{1}{2}$, the right-hand side becomes

$$\text{Lt}_{l \rightarrow \infty} \int_0^\infty \frac{l^{l+1}}{l} v^l e^{-lv} \phi(uv) dv = \phi(u)$$

as it is known (Widder, 1934) that for almost all positive u ,

$$\text{Lt}_{n \rightarrow \infty} \frac{n^{n+1}}{n} \int_0^\infty y^n e^{-ny} \{\phi(uy) - \phi(u)\} dy = 0.$$

Hence for almost all positive u

$$\begin{aligned} \phi(u) &= \text{Lt}_{l \rightarrow \infty} \left[\frac{\frac{1}{u} U_q \{f(s)\}}{l-1} \right]_{s=\frac{l}{u}} \\ &= \text{Lt}_{q \rightarrow \infty} V_q[f(u)]. \end{aligned}$$

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SUMMARY.

Dr. R. S. Varma has recently given a generalization of the Laplace transform

$$f(s) = \int_0^\infty e^{-st} d\alpha(t)$$

in the form

$$f(s) = \int_0^\infty (st)^{m-\frac{1}{2}} e^{-\frac{1}{2}st} W_{k, m}(st) d\alpha(t)$$

which assumes the form

$$f(s) = \int_0^\infty (st)^{m-\frac{1}{2}} e^{-\frac{1}{2}st} W_{k, m}(st) \phi(t) dt$$

when $\alpha(t)$ is absolutely continuous. Three inversion formulae for this generalized Laplace transform have been obtained in this paper—one by making use of the Mellin's Inversion Formula, second by using a result in the theory of Stieltjes transform due to Widder, and third by employing a set of differential operators.

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A QUASI-LATTICE THEORY OF REAL GASES AND OF STRONG ELECTROLYTES IN SOLUTIONS ¹

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INTRODUCTION.

In usual theories of specific heats and the like for crystalline bodies, atoms (or ions) are generally assumed to vibrate, in a regular manner, about their equilibrium positions which form a regular three-dimensional lattice. But, this simple picture has not been found suitable for explaining other group of phenomena like the evaporation of a crystal, the dissolution of a crystal in liquid media, the mutual diffusion of crystalline bodies, etc. For explaining these phenomena, Frenkel and others (Frenkel, 1946) have proposed a modified picture for the structure of crystalline bodies. In this modified picture, atoms (or ions) do not, by themselves, form a regular lattice, but even then a regular lattice may be considered as formed by atoms (or ions) together with the vacant sites (caused by the evaporation or the displacement of atoms or ions), which are generally referred to as the 'holes', and are to be counted as some sort of physical entities entering into calculations like the atoms (or ions) themselves. Thus the crystalline bodies are looked upon as some sort of binary alloys of atoms (or ions) and 'holes'. As in alloys, the ratio of the number of atoms (or ions) and 'holes' is taken to be capable of all possible variations. Of course, the number of holes in the system is generally taken to increase with the temperature.

Lennard-Jones and Devonshire (1937) have investigated important thermodynamic behaviours of normal liquids, viz., coefficients of thermal expansion, the heat of fusion, etc., from a picture for the structure of normal liquid, similar to that delineated above. According to them, the structure of normal liquids may be looked upon as a sort of alloy of atoms and 'holes' and the essential difference of the picture for normal liquids from that of solid is that in solids there is a long-distance order (in arrangements) but in the liquids the long-distance order disappears and only short-distance order is conspicuous.

In the present paper, it will be shown that the usual expressions for thermodynamic functions of real gases and useful formulae for distributions of ions of strong electrolytes in solutions can be obtained from similar pictures for their structures. Here, real gases and ions of strong electrolytes in solutions will be looked upon as sorts of alloys of molecules (atoms or ions) and 'holes' extended over the entire volume of the enclosure or of the solutions. The number of lattice-points in volume V will be taken as V/b , where b is different for different molecules (atoms or ions) due to the existence of an (average) minimum approach, either for the finite dimension of molecules or for the mutual repulsive interaction amongst molecules (atoms or ions) or for some other similar reasons. Of these V/b lattice-

¹ This paper comprises the main thoughts and results of a thesis with the same title, submitted to the University of Calcutta in November, 1951. A note containing the main thoughts of the paper was communicated to Indian Science Congress on 15th July, 1951, and was read at its annual session in January, 1952.

points, N are to be taken as occupied by N molecules (atoms or ions), and the rest, $V/b - N$, are occupied by the 'holes'. Along with Lennard-Jones and Devonshire, the interchanges of the mutual positions in the lattice are to be taken as frequent (of course, in the present case, they are more frequent than in case of liquids). The total number of possible arrangements of molecules (atoms or ions) and holes will be termed as the configurational thermodynamic probability (corresponding to the configurational entropy). The total thermodynamic probability will be taken as the product of the usual expression for thermodynamic probability (calculated after Planck and Lorentz but for distributions with respect to kinetic energy only and referred here as momental thermodynamic probability) and the expression of the configurational thermodynamic probability. In this way, the full information about the deviation from ideal gases (in case of real gases) and from ideal solutions (in case of solutions of strong electrolytes) which can be attributed to the existence of an (average) minimum approach can be obtained simply and directly.

To fit the usual concept of randomness (of gas-theories) with the present theory, one is to remember the important remarks (of course, originally made for real metallic alloys) of Bethe (1935). The arrangements, having large number of realisations, are expected to be of most frequent occurrences, in spite of its higher energy, causing the disappearance of correlations of distant atoms. In the present case (which is really an extreme case where the binding energy is very small), the disappearance of the correlations of atoms (distant and near) is quite natural and is to be interpreted as the usual randomness in gases. In these cases, according to Bethe, the number of possible realisation of arrangements of atoms (i.e., the configurational thermodynamic probability) is more important than the energies of arrangements.

Now, apart from the existence of an average minimum approach of the molecules, the other factor, to which the characteristic behaviour of real gases is generally attributed, is the effect of the field of forces, external or due to mutual interactions amongst molecules themselves or amongst the molecules and the boundary walls. To extend the present treatment, proposed above, to these cases, a simple restriction to be imposed on the nature of fields of forces is that the field of force will have, at least, in average a potential, the gradient of which can be supposed to be so small that any change of forces within a distance of molecular dimension can be neglected. Thus, the space within the enclosure of volume V can be divided into layers of constant potential energies (at least, in average), and the portions of the system, under consideration, in different potential-energy layers will be looked upon as different alloys of molecules and holes, of similar lattice-pattern, which are in phase equilibrium with one another. Here, it is to be admitted that the division of the configurational space into layers of constant potential energies (in average) is subject to some theoretical objections, as the potential energy may depend on the instantaneous distributions of particles. In case of external field or in case of slowly varying long-ranged forces or the like this division of the potential energy layers is quite permissible. But in case of other fields of forces, mainly due to mutual interactions amongst the molecules themselves, the validity of division of the configurational space is not above criticisms. In support of the procedure, proposed above, it can be added that similar ideas of existence of layers of some (average) constant potential energies *ab initio* is common amongst other successful statistical theories of real gases, specially in the presence of long-ranged forces (Fowler, 1936).

As it is well known, the Vant Hoff's law of osmotic pressure for ideal solution is generally explained from an ideal gas-like structure for the solutes in ideal solutions. The deviations of the osmotic and the allied properties of real solutions are generally explained in a way similar to that used for explaining the deviations of properties of real gases from those of ideal gases. So in the present paper, the ions of strong electrolytes in solutions have been treated similarly, as a system of alloys of ions and holes under a long-ranged field due to Coulomb's interactions

between ions and the laws¹ for distribution of ions in the solutions, similar to those empirical laws which Bagchi (1950) has shown to yield a better agreement of the theoretical and the experimental values for activity coefficients, have been obtained.

SEC. A. GAS OF MOLECULES OF FINITE DIMENSIONS.

To have a clear understanding of the method, the simplest type will be considered first. The real gas of the simplest type is the gas which is composed of molecules of finite dimensions (or of molecules, under such a field of force that the effect can be accounted for from the assumption of the existence of an average minimum approach), and in which the effect of other field of forces (internal or external) on the thermodynamic behaviour of the system is insignificant and so can be neglected.

For this, let us consider an enclosure of volume V , containing N molecules, each of which is supposed to possess a volume of exclusion, b . It is assumed that there is no association or dissociation amongst the molecules in the assembly.

As already proposed, the system will be assumed to be composed of N molecules and $\frac{V}{b} - N$ 'holes' distributed amongst $\frac{V}{b}$ lattice-points. Then, the configurational thermodynamic probability is

$$\frac{\left(\frac{V}{b}\right)!}{N! \left(\frac{V}{b} - N\right)!} \quad \dots \quad \dots \quad \dots \quad (1)$$

The momental thermodynamic probability, calculated after Planck-Lorentz, is,

$$\frac{N!}{\prod_i a_i!}, \quad \dots \quad \dots \quad \dots \quad (2)$$

where a_i is the number of molecules having the kinetic-energy ϵ_i .

Then, the total thermodynamic probability is

$$\frac{\left(\frac{V}{b}\right)!}{\left(\frac{V}{b} - N\right)! \prod_i a_i!} \quad \dots \quad \dots \quad \dots \quad (3)$$

This expression for thermodynamic probability is the same as that obtained previously in a paper (Dutta, 1946), and, so, the usual expression for thermodynamic functions for real gases of the type considered here are to be obtained by the method based on Boltzmann principle as in the paper (*loc. cit.*). These expressions are

$$a_i = e^{\lambda - \frac{\epsilon_i}{kT}}, \quad \dots \quad \dots \quad \dots \quad (4)$$

$$E = \frac{3}{2} N k T, \quad \dots \quad \dots \quad \dots \quad (5)$$

¹ Recently, Eigen and Wicke, in a note (Die Naturwissenschaften, Vol. 38, p. 445), have obtained good fit for activity coefficients from a distribution formula which they have claimed as new, but which is only a special form of the present laws as shown by the author (in Die Naturwissenschaften, Vol. 39, p. 108).

$$S = Nk \left[\frac{3}{2} + \log V + \frac{3}{2} \log T + \log \left\{ \frac{b}{h^3} (2\pi mk)^{\frac{3}{2}} \right\} - \log N - \frac{V}{Nb} \left(1 - \frac{Nb}{V} \right) \log \left(1 - \frac{Nb}{V} \right) \right], \quad \dots \quad (6)$$

$$\Psi = S - \frac{E}{T} = \left[\log V + \frac{3}{2} \log T + \log \left\{ \frac{b}{h^3} (2\pi mk)^{\frac{3}{2}} \right\} - \log N - \frac{V}{Nb} \left(1 - \frac{Nb}{V} \right) \log \left(1 - \frac{Nb}{V} \right) \right], \quad (7)$$

$$p = - \frac{kT}{b} \log \left(1 - \frac{Nb}{V} \right). \quad \dots \quad (8)$$

This is the Planck-Saha-Bose Equation of state for real gases when the effect of the field can be ignored.

In the limiting case, $\frac{Nb}{V} \rightarrow 0$, the above expressions become:

$$S = Nk \left[\frac{3}{2} + \frac{3}{2} \log T + \log \left\{ \frac{1}{N} \frac{(2\pi mk)^{\frac{3}{2}}}{h^3} \right\} \right], \quad \dots \quad (9)$$

and

$$p = \frac{NkT}{V}. \quad \dots \quad (10)$$

These are the usual expressions for ideal gases. Up to the first approximation, these become:

$$S = Nk \left[\frac{5}{2} + \frac{3}{2} \log T + \log V - \frac{1}{2} \frac{Nb}{V} + \log \left\{ \frac{(2\pi mk)^{\frac{3}{2}}}{h^3} \right\} \right], \quad \dots \quad (11)$$

and

$$p = \frac{NkT}{V} \left[1 + \frac{1}{2} \frac{Nb}{V} \right] = \frac{NkT}{V - \beta}, \quad \dots \quad (12)$$

where

$$\beta = \frac{1}{2} Nb. \quad \dots \quad (13)$$

SEC. B. VAN DER WAAL'S GAS.

Before proceeding with general discussion of real gases under any field of forces, we shall consider the gas under Van der Waal's field of forces. In this case, the forces between the molecules, the effects of which have not been considered along with the repulsive forces considered in the above section, are taken to be short-ranged forces of attraction depending on their mutual distances. So, about every molecule, there is a sphere of action of molecular interaction such that only those molecules which came within this sphere will produce any significant influence on the molecule under consideration. Thus, in the interior of the gas, it can be taken that there is a symmetrical molecular distribution within a sphere of action of molecular interaction such that the resultant force of attraction on the molecule at the centre is zero, and thus molecules in the interior will have a constant potential energy. For molecules in the surface layer, due to the intersections of the sphere of action

of attraction by the boundary-walls, the distribution of molecules within the sphere of action about the molecule under consideration is not spherically symmetrical, and so, the resultant force on the molecule is not zero. Thus, the potential energies of molecules in the surface-layer will be different from those in the interior. Of course, there will be a variation of potential energies within the surface-layer; but for the sake of simplicity of calculation, we shall neglect the variation. We shall assume that the potential energies of molecules in the surface-layer is, at least in average, the same in the layer and is different from that of the interior.

As proposed in the introduction, we shall suppose that the system under consideration is composed of two alloys of molecules and holes, one occupies the interior and the other, the surface layer and they are in phase-equilibrium.

Let V_1, V_2 be the volumes of the interior and the surface-layer containing, at any instant, N_1, N_2 molecules of potential energies, w_1, w_2 respectively. Then, the thermodynamic probability becomes (according to the suggestions stated above)

$$W = \Pi \frac{\left(\frac{V_i}{b}\right)!}{\left(\frac{V_i}{b} - N_i\right)! \Pi a_{i1}!}, \quad (i = 1, 2), \quad \dots \quad (14)$$

where a_{11} and a_{21} are numbers of molecules in the interior and in the surface layer with kinetic energies ϵ_1 .

From this, the expressions for usual thermodynamic functions and for microscopic distributions can be simply obtained, by the method based on Boltzmann's principle as

$$\frac{a_{i1}}{\frac{V_i}{b} - N_i} = e^{-\lambda' - \frac{\epsilon_1 + w_i}{kT}}, \quad \dots \quad (15)$$

$$N_i = \frac{V_i}{b} \cdot \frac{1}{e^{\lambda' + \frac{w_i}{kT}} + 1}, \quad \dots \quad (16)$$

$$a_i = a_{i1} + a_{21} = e^{-\lambda - \frac{\epsilon_i}{kT}}, \quad \dots \quad (17)$$

and

$$\begin{aligned} \Psi = k \left[- \left(\frac{V - V_2}{b} \right) \left\{ 1 - \frac{Nb}{V - V_2 \left(1 - e^{-\frac{w}{kT}} \right)} \right\} \log \left\{ 1 - \frac{Nb}{V - V_2 \left(1 - e^{-\frac{w}{kT}} \right)} \right\} \right. \\ \left. - \frac{V_2}{b} \left\{ 1 - \frac{Nb e^{-\frac{w}{kT}}}{V - V_2 \left(1 - e^{-\frac{w}{kT}} \right)} \right\} \log \left\{ 1 - \frac{Nb e^{-\frac{w}{kT}}}{V - V_2 \left(1 - e^{-\frac{w}{kT}} \right)} \right\} \right. \\ \left. + N \log V + N \log \left\{ 1 + \frac{V_2}{V} \left(1 - e^{-\frac{w}{kT}} \right) \right\} - N \frac{w_1}{kT} + N \log \left\{ \frac{1}{N} \frac{(2\pi mkT)^{\frac{3}{2}}}{h^3} \right\} \right] \dots \quad (18) \end{aligned}$$

where

$$w = w_2 - w_1 \quad \dots \quad (19)$$

Now, as in the paper (Dutta, 1948), when the field is weak and short-ranged (which is generally taken to be the case for Van der Waal's field), $\frac{V_2}{V}$ and $\frac{w}{kT}$ are small. So the expression for Ψ can be expanded in powers of $\frac{V_2}{V}$ and $(1 - e^{-\frac{w}{kT}})$ and terms containing second and higher powers of $\frac{V_2}{V}$ and $(1 - e^{-\frac{w}{kT}})$ can be neglected. Then we have

$$\Psi = k \left[- \left(\frac{V}{b} \right) \left(1 - \frac{Nb}{V} \right) \log \left(1 - \frac{Nb}{V} \right) + N \log V + N \frac{V_2}{V} \left(1 - e^{-\frac{w}{kT}} \right) - N \frac{w_1}{kT} + N \log \left\{ \frac{1}{N} \frac{(2\pi mkT)^{\frac{3}{2}}}{h^3} \right\} \right]. \quad (20)$$

Then,

$$\begin{aligned} p &= T \left(\frac{\partial \Psi}{\partial V} \right)_T \\ &= NkT \left[- \frac{1}{Nb} \log \left(1 - \frac{Nb}{V} \right) - \frac{1}{V} \left\{ \left(\frac{\partial V_2}{\partial V} \right)_T - \frac{V_2}{V} \right\} \left(1 - e^{-\frac{w}{kT}} \right) - \frac{V_2}{V} e^{-\frac{w}{kT}} \frac{1}{kT} \left(\frac{\partial w}{\partial V} \right)_T - \frac{1}{kT} \left(\frac{\partial w_2}{\partial V} \right)_T \right], \dots \quad (21) \end{aligned}$$

or

$$p + \frac{\alpha}{V^2} = - \frac{kT}{b} \log \left(1 - \frac{Nb}{V} \right), \quad \dots \quad (22)$$

where

$$\begin{aligned} \alpha &= NkT \left[\left\{ V \left(\frac{\partial V_2}{\partial V} \right)_T - V_2 \right\} \left(1 - e^{-\frac{w}{kT}} \right) + \frac{V_2}{kT} e^{-\frac{w}{kT}} \cdot V \cdot \left(\frac{\partial w}{\partial V} \right)_T + \frac{V^2}{kT} \left(\frac{\partial w_1}{\partial V} \right)_T \right] \dots \quad (23) \end{aligned}$$

The equation (21) is the Planck-Saha-Bose equation of state for Van der Waal's gas (Mazumdar, 1929). Now, if the expressions (20) and (21) are expanded in powers of $\left(\frac{Nb}{V} \right)$ and if $\left(\frac{Nb}{V} \right)^2$ and higher powers are neglected, then we have

$$\begin{aligned} \Psi &= Nk \left[\frac{3}{2} \log T + \log V - \frac{1}{2} \frac{Nb}{V} - \frac{V_2}{V} \left(1 - e^{-\frac{w}{kT}} \right) + 1 - \log N - \frac{w_1}{kT} + \log \left\{ \frac{(2\pi mk)^{\frac{3}{2}}}{h^3} \right\} \right], \dots \quad (24) \end{aligned}$$

and

$$p + \frac{\alpha}{V^2} = \frac{NkT}{V} \left[1 + \frac{1}{2} \frac{Nb}{V} \right] = \frac{NkT}{V - \beta}, \quad \dots \quad (25)$$

Evidently, β ($= \frac{1}{2}Nb$) is independent of T and V , and α is a function of T , V . Now, as in the paper (Dutta, II, 1948), when suitable assumption for the field is introduced, α can be shown to be independent of T and V up to the first approximation. Then, the equation (24) is the usual form of Van der Waal's equation of State for real gas.

SEC. C. CALCULATIONS OF HIGHER VIRIAL COEFFICIENTS IN THE EQUATIONS OF STATES.

When more accurate expressions for the equations of state for real gases are required, then after starting from the equation (20), the higher virial coefficients of the equations of states can be calculated from considerations of the overlapping of the 'Deckung-sphären', by a method similar to that developed in one of the previous papers (Dutta, 1952) of the author.

SEC. D. REAL GASES OF GENERAL TYPE.

Now, we shall extend our discussions to the case of real gases under a field of force of general types (of course, subject to the restrictions mentioned in the introduction). As suggested in the introduction, the space within the volume is taken to be divided into layers of volumes $V_1, V_2, \dots, V_i, \dots$ at any instant, containing $N_1, N_2, \dots, N_i, \dots$ molecules with potential energies $w_1, w_2, \dots, w_i, \dots$ respectively. The system, under considerations, will be considered as composed of simpler constituent systems, (similar to that considered in the section A), occupying the volumes $V_1, V_2, \dots, V_i, \dots$ and these simpler systems are taken to be in phase-equilibrium. Then, the thermodynamic probability for the constituent system in the i -th layer is

$$\frac{\left(\frac{V_i}{b}\right)!}{\left(\frac{V_i}{b} - N_i\right)! \Pi_i \alpha_{i!}}, \quad \dots \quad \dots \quad \dots \quad (26)$$

where $\alpha_{i!}$ is the number of molecules in the i -th layer and with the kinetic energy ϵ_i .

Then, the total thermodynamic probability for the entire system, under considerations, is

$$W = \Pi_i \frac{\left(\frac{V_i}{b}\right)!}{\left(\frac{V_i}{b} - N_i\right)! \Pi_i \alpha_{i!}}, \quad \dots \quad \dots \quad \dots \quad (27)$$

This expression (26) for the thermodynamic probability is same as that obtained previously in one of the papers (Dutta, 1951), and so, the expression for usual thermodynamic functions can be obtained by the method, based on Boltzmann's principle, as shown in the paper (*loc. cit.*). The equation of state, obtained in this case, is

$$p(V - \beta') = NkT e^{-\frac{\alpha'}{NkTV}}, \quad \dots \quad \dots \quad \dots \quad (28)$$

where β' , α' in general are functions of temperature and volume. When suitable assumptions about the nature of the field are introduced, then β' reduces to β and α' can be shown to have the form as required in the equation of states of Dieterici.

SEC. E. MIXTURE OF REAL GASES OF THE SIMPLEST TYPE.

In order to consider the mixture of real gases of the simplest type (similar to those considered in section A), it will be assumed that there are two mutually interpenetrating lattices of lattice-points $\frac{V}{b_1}$ and $\frac{V}{b_2}$ as possible sites for molecules of type (1) and (2) respectively, where b_1, b_2 are the volumes of exclusions of molecules of type (1) and (2) amongst their own type. Now, along with b_1, b_2 , another quantity b_{12} will be introduced to represent the volume of exclusion of one type with respect to the other. Then $\frac{V-N_1b_{12}}{b_2}$ will be taken as number of lattice-points available for distributing molecules of type (2) when molecules of type (1) are already distributed. Similarly, $\frac{V-N_2b_{12}}{b_1}$ are the same for molecules of type (1) when molecules of type (2) have already been distributed.

Then, the thermodynamic probability for the system under consideration, (when the effect of the fields of forces other than the effect of which can be accounted for from the assumption of an average minimum approach can be ignored), is to be written as

$$W_{12} = \frac{\left(\frac{V}{b_1}\right)!}{\left(\frac{V}{b_1} - N_1\right)!} \frac{\left(\frac{V - N_1b_{12}}{b_2}\right)!}{\left(\frac{V - N_1b_{12}}{b_2} - N_2\right)!} \prod_i a_i! \prod_i c_i! \quad (29)$$

where a_i and c_i are the number of molecules of types (1) and (2) with kinetic energies ϵ_i and η_i respectively.

Here, it is to be noted that the expression (28) is not symmetrical with respect to N_1, N_2, b_1, b_2 characteristic quantities for molecules of types (1) and (2). This is due to the fact that in writing the expression (28), the molecules of type (1) are taken to be distributed first and the others, after that what type of molecules has occupied the volume is not generally known. Moreover, in an equilibrium theory, this fact appears to be of no interest. This selection of molecules of one type, as distributed earlier than the other, is artificial one and has been introduced only for convenience of calculations. On the other hand, from physical considerations, it is expected that the expression for thermodynamic probability should be symmetrical. To symmetricise this expression, we shall take

$$\log W = \frac{1}{2} (\log W_{12} + \log W_{21}), \quad \dots \quad (30)$$

where W_{21} is the thermodynamic probability calculated assuming the molecules of type (2) to be distributed earlier than those of type (2).

The expression for $\log W$, obtained here, is same as that of a previous paper (Dutta, IV, part I, 1951), and so, as in the paper, the expressions for usual thermodynamic functions can be obtained by the method based on Boltzmann principle. The equation of states, obtained in this case, is

$$p = \frac{NkT}{V} \cdot \frac{1}{2} \cdot \left[-\frac{V}{Nb_1} \left\{ \log \left(1 - \frac{c_1 Nb_1}{V} \right) + \log \left(1 - \frac{c_1 Nb_1}{V - c_2 Nb_{12}} \right) \right\} \right. \\ \left. - \frac{V}{Nb_2} \left\{ \log \left(1 - \frac{c_2 Nb_2}{V} \right) + \log \left(1 - \frac{c_2 Nb_2}{V - c_1 Nb_{12}} \right) \right\} \right], \quad \dots \quad (31)$$

where

$$c_1 = \frac{N_1}{N}, \quad c_2 = \frac{N_2}{N}, \quad N = N_1 + N_2. \quad \dots \quad (32)$$

This is the form of Planck-Saha-Bose equation of states for mixture of real gases of simplest type.

$$\text{From gases, } \frac{V}{N_1 b} \text{ and } \frac{V}{N_2 b} > > 1, \quad \dots \quad (33)$$

so that up to the zeroth approximation, we have

$$p = \frac{NkT}{V}, \quad \dots \quad (34)$$

and up to the first approximation, we have

$$\begin{aligned} p &= \frac{NkT}{V} \left[1 + c_1^2 \cdot \frac{1}{2} \frac{Nb_1}{V} + 2c_1c_2 \cdot \frac{1}{2} \frac{Nb_{12}}{V} + c_2^2 \cdot \frac{1}{2} \frac{Nb_2}{V} \right] \\ &= \frac{NkT}{V} \left[1 + \frac{c_1^2\beta_1 + 2c_1c_2\beta_{12} + c_2^2\beta_2}{V} \right] \\ &= \frac{NkT}{V} \left[1 + \frac{\beta}{V} \right] = \frac{NkT}{V - \beta}. \quad \dots \quad (35) \end{aligned}$$

This is the usual equation of state for gases of finite dimension, and β has the same form as suggested by Lorentz (1927).

SEC. F. MIXTURE OF VAN DER WAAL'S GASES.

In this case, as in the case of simple Van der Waal's gas, the system, under considerations, will be taken as composed of two simpler constituent systems (of the type considered in the preceding section), one occupying the interior and the other the surface-layers. Then, the thermodynamic probability will be obtained as

$$\log W = \frac{1}{2} (\log W_{12} + \log W_{21}), \quad \dots \quad (36)$$

where

$$\begin{aligned} W_{12} &= \prod_i \frac{\left(\frac{V_i}{b_1}\right)!}{\left(\frac{V_i}{b_1} - N_{1i}\right)! i! a_{1i}!} \cdot \frac{\left(\frac{V_i - N_{1i} b_{12}}{b_2}\right)!}{\left(\frac{V_i - N_{1i} b_{12}}{b_2} - N_{2i}\right)! i! c_{1i}!}, \\ &\quad (i = 1, 2). \quad \dots \quad (37) \end{aligned}$$

In the above, N_{11} and N_{21} are number of molecules of types (1) and (2) respectively in the interior; N_{12} and N_{22} are those in the surface-layers, a_{1i} and c_{1i} are the number of molecules of both types in the interior and with kinetic energies ϵ_i and η_i respectively; and a_{2i} and c_{2i} are the similar quantities in the surface-layers.

Here, $\log W$ has the same expression as that obtained in a previous paper (Dutta, IV, part 2, 1951) and so, as in that paper, the expression for usual thermo-

dynamic functions can be obtained by the method, based on Boltzmann's principle. The equation of states, obtained up to the first approximation, is

$$p + \frac{\alpha}{V_2} = \frac{NkT}{V - \beta}, \quad \dots \quad (38)$$

where

$$\beta = c_1^2 \beta_1 + 2c_1 c_2 \beta_{12} + c_2^2 \beta_2, \quad \dots \quad (39)$$

and

$$\alpha = c_1^2 \alpha_1 + 2c_1 c_2 \alpha_{12} + c_2^2 \alpha_2. \quad \dots \quad (40)$$

This is the Van der Waal equation of states for mixture of real gases as suggested by Lorentz (1927).

SEC. G. MIXTURE OF REAL GASES OF GENERAL TYPES.

Our present discussion can be directly and straightforwardly extended to the case of the mixture of real gases under any field of forces (of course, subject to the restrictions mentioned in the introduction). Here, the system, under consideration, will be taken as composed of a number of simpler constituent systems (of the type, discussed in section E) occupying different potential-energy layers. After introducing suitable symbols similar to those in the sections D and F, the thermodynamic probability can be written as

$$\log W = \frac{1}{2} (\log W_{12} + \log W_{21}), \quad \dots \quad (41)$$

where

$$W_{12} = \prod_i \frac{\left(\frac{V_i}{b_1}\right)!}{\left(\frac{V_i}{b_1} - N_{1i}\right)!} \cdot \frac{\left(\frac{V_i - N_{1i} b_{12}}{b_2}\right)!}{\left(\frac{V_i - N_{1i} b_{12}}{b_2} - N_{2i}\right)!} \cdot \prod_i a_{ii}! \cdot \prod_i c_{ii}! \quad \dots \quad (42)$$

The expression (40) for the thermodynamic probability is the same as that obtained in the paper (Dutta, IV, part 3, 1951), and so, the expressions for usual thermodynamic functions can be obtained by the method based on Boltzmann's principle, as shown in that paper (*loc. cit.*). The equation of states, as shown there after proper simplifications and assumptions can be put in the form,

$$p = NkT \left\{ c_1 \frac{e^{-\frac{\alpha_1}{NkTV}}}{V - \gamma_1} + c_2 \frac{e^{-\frac{\alpha_2}{NkTV}}}{V - \gamma_2} \right\} \cdot \dots \quad (43)$$

This is to be regarded as the Dieterici's equation of states for mixture of real gases.

SEC. H. DISTRIBUTION OF IONS OF STRONG ELECTROLYTES IN SOLUTIONS.

Bagchi (1950) has shown that a better and closer fit between the theoretical and the experimental values of the activity-coefficients is obtained, if in the Debye-Hückel theory of strong electrolytes in solutions a new distribution formula is taken in place of that of Boltzmann. The distribution formula assumed by Bagchi is

$$n_+ = \frac{N}{B_+ \exp\left(\frac{e + \psi}{kT}\right) + 1}, \quad \dots \quad (44)$$

$$n_{-} = \frac{N}{B_{-} \exp\left(\frac{\epsilon_{-}\psi}{kT}\right) + 1}, \quad \dots \quad (45)$$

where n_{+} and n_{-} are concentrations of positive and negative ions of charges ϵ_{+} and ϵ_{-} respectively, where ψ is the electric potential, K is the Boltzmann's constant, T the absolute temperature, and N the total number of ions per unit volume of solution; B_{+} and B_{-} are some suitable constants.

To consider the distributions of ions in solutions, it is to be remembered that in nature, the common electrolytes in the solid-phase exist as crystals. Now, as in the Debye-Hückel theory (Hückel, 1924), if we assume that by introduction of dielectric constants in the calculations of the electric field of the ions, the effect of the solvent can be accounted for, then the dissolution of the crystals of strong electrolytes in solvents may be worked upon as the slowly filling up of the intermediate space within the lattice by a dielectric medium. Now the binding forces between the molecules in a lattice tend to establish an order and the kinetic motions of the molecules try to produce disorder. Now, for the filling up of the intermediate space in a crystal by dielectric medium the binding force will diminish whereas the kinetic motions remain unaltered. As a consequence, the crystal will begin to be distorted and ultimately will appear to be of the type of distorted crystal discussed by Frenkel (1942), i.e., to be a sort of alloys of molecules and holes. Thus, the method, developed above, can be applied for treating the behaviour of ions of strong electrolytes in solutions.

Let $V_1, V_2, \dots, V_i, \dots$ be volumes of potential layers of potentials, $\psi_1, \psi_2, \dots, \psi_i, \dots$ respectively in average. Let, at any instant, $N_1^{+}, N_2^{+}, \dots, N_i^{+}, \dots$ and $N_1^{-}, N_2^{-}, \dots, N_i^{-}, \dots$ be the numbers of positive and negative ions in layers of volumes $V_1, V_2, \dots, V_i, \dots$ respectively. As in previous cases, the entire system will be taken to be composed of simpler constituent systems, occupying different potential layers. Then, as in (39) and (40), the thermodynamic probability will be written as

$$\log W = \frac{1}{2} (\log W_{++} + \log W_{--}), \quad \dots \quad (46)$$

where

$$W_{+} = \Pi_i \frac{\left(\frac{V_i}{b_{+}}\right)!}{\left(\frac{V_i}{b_{+}} - N_i^{+}\right)!} \frac{\left(\frac{V_i - N_i^{+} b_{+}}{b_{-}}\right)!}{\left(\frac{V_i + N_i^{+} b_{+}}{b_{-}} - N_i^{-}\right)!} \frac{\Pi_i a_{+}^{N_i^{+}}}{\Pi_i a_{-}^{N_i^{-}}}, \quad \dots \quad (47)$$

and similar expression is for W_{--} .

Then, by calculations, similar to those in one of the previous papers (Dutta and Bagchi, 1950), one obtains, for concentrations corresponding to potential ψ_i ,

$$n_i^{+} = \frac{\frac{1}{b_{+}}}{B_{+} e^{\frac{\epsilon_{+}\psi_i}{kT}} + 1} \quad \dots \quad (48)$$

$$n_i^{-} = \frac{\frac{1}{b_{-}}}{B_{-} e^{\frac{\epsilon_{-}\psi_i}{kT}} + 1} \quad \dots \quad (49)$$

$\frac{1}{b_{+}}$ and $\frac{1}{b_{-}}$ are numbers of lattice points per unit volume of the solution. Bagchi

in his papers, written earlier than the paper referred to above, has taken empirically and for simplicity of calculations

$$\frac{1}{b_+} = \frac{1}{b_-} = N = \text{total number of ions present per unit volume (48).}$$

CONCLUSION.

In microscopic theory of matter, we usually consider two types of problems, viz., one, of the crystals and the like, is of perfect order, and the other, of gases and the like, is of perfect randomness. The transitions from states of perfect order to perfect disorder are not yet clearly visualised in the microscopic theories, up till now. The quasi-lattice-theory for real gases and for ions of strong electrolytes in solution, as developed in the present paper, along with that for solid of Frenkel and others and with that for liquid of Lennard-Jones and others, shows the possibility of divisions of an unified picture for the structure of matter in different phases.

SUMMARY.

In the present paper, a quasi-lattice theory, similar to the theory of solids developed by Frenkel and others, and to that of liquid by Lennard-Jones and Devonshire, has been developed for real gases and ions of strong-electrolytes in solutions. In the present theory, the systems of real gases and ions of strong electrolytes in solutions are taken as sorts of alloys of the molecules (atoms or ions) and the holes. From this picture and by the method of Planck and Lorentz based on Boltzmann's principle, expressions for usual thermodynamic functions and laws of microscopic distributions have been deduced.

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MICROFOSSILS FROM THE UPPER VINDHYANS, WITH A DISCUSSION ON THE AGE OF THE VINDHYANS IN THE LIGHT OF PLANT-FOSSIL DISCOVERIES

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INTRODUCTION.

The work embodied in this paper forms a part of the programme of palaeobotanical investigations sponsored by the Committee on the Measurement of Geological Time in India. The formations constituting the Vindhyan system are among the oldest sedimentary rocks of India. The vast strata of sandstones, shales and limestones attain a total thickness of over 14,000 ft. and are almost barren of organic remains. This paucity of the fossil record is significant, for the strata exhibit little evidence of metamorphism and other structural disturbances and are thus well suited to the preservation of life. The name Vindhyan system was proposed in 1856 by T. Oldham. The system has been included by Holland (1926, pp. 12-13) within his *Purana* group. This group was instituted for all the unfossiliferous peninsular formations resting above the Archaen-Dharwar complex and is regarded by Holland as pre-Cambrian in age. Vredenburg believed the Vindhyan system to be Cambrian on the basis of a rough lithological semblance between its rocks and the fossiliferous Cambrian strata of the Salt Range (Holland, *loc. cit.*, pp. 13-14). From the point of view of homotaxis great interest attaches to the question of the occurrence of fossils in the Vindhyan. A few remains have been found which, there is good reason to believe, are really organic. It has been suggested that if that is so, at least a part of Vindhyan system may have to be included in the Cambrian (Wadia, 1939; Reed, 1949). The system is divided into four main series (Holland, *loc. cit.*, pp. 177-179; Krishnan, 1949) as follows:—

Upper Vindhyan ..	{	Bhander Series.
		Rewa Series.
		Kaimur Series.
Lower Vindhyan ..		Semri Series.

There are two distinct facies. The Semri series is marine and mainly calcareous. The Bhander, Rewa, and the Kaimur series are mainly arenaceous, of fluvatile or estuarine origin.

PREVIOUS RECORDS OF LIFE IN THE VINDHYANS.

In 1908 H. C. Jones discovered small discoid bodies (1.5 mm.-4.5 mm. in diameter) in the dark-coloured Suket shales which form the base of the Kaimur series near Neemuch in Central India. Later similar specimens were also collected from another nearby locality named Rampura. These were described by Chapman (1935) under two new genera, *Fermoria* and *Protobolella* which he regarded as belonging to the order Atremata. Chapman recognised three species of *Fermoria* (*F. minima*, *F. granulosa*, and *F. capsella*) and one of *Protobolella* (*P. jonesi*). M. R. Sahni (1936) has cast doubt on the affinity of these fossils with the brachiopods. He has combined *Fermoria* and *Protobolella* in one genus *Fermoria* and suggested Chapman's different species in the single species *Fermoria minima*. Sahni suggests raising this group of fossils to the rank of a new family, *Fermoriidae*, of undetermined relationship.

Although the organic nature of the fossils discovered by Jones cannot be subjected to doubt, their position within the animal kingdom is not uncontested. B. F. Howell regarded them as plants (Chapman, *loc. cit.*, pp. 113-114) and compared them tentatively with the Middle Cambrian blue-green alga, *Morania* of Walcott. The test of incineration provided support for his view that the specimens were plant remains; in contrast the shell of a Middle Cambrian phosphatic specimen of *Acrothele* did not burn. Carbonisation, however, does not invariably indicate plant matter. According to Chapman (*loc. cit.*, p. 112) chitin gets carbonised like any plant matter, and he cites the examples of the carbonised carapace of *Marella* from the Middle Cambrian of British Columbia and valves of *Lingula* and *Lingulella* which are known to get converted into anthracite.

In the Rohtas limestone (Semri series) at Banjari in the Sone valley R. C. Misra and G. S. Bhatnagar (1950) have discovered carbonaceous structures of a roughly circular outline. The average diameter of the specimens is 26 mm. which is nearly four times that of the discoid fossils collected by Jones. Misra and Bhatnagar regard their specimens to be plant remains.

In 1946 K. P. Rode described a number of conical shell-like structures which he referred to a new species, *Hyolithes rohtaswei*. The specimens were found in the limestone at the top of the Rohtas stage in the Sone valley, three miles west of Ramdhera.

Dark spherical bodies measuring up to 145μ have been observed by Misra and Bhatnagar (*loc. cit.*) in thin sections of the Vindhyan limestones. They have been found in the glauconitic limestone of the Lodhwara hill north of Karwi, and in the Rohtas limestone from Banjari. The authors compare these bodies with 'algal dust' described in 1941 by Alan Wood (cited by Misra and Bhatnagar, 1950) from the Carbonaceous limestones of England. In the Lodhwara hill limestone Misra (1949) has also seen small rounded, ovoid, or sausage-shaped bodies filled with glauconite. The walls of these bodies are said to be carbonised, and Misra considers them to be casts of some organisms. In thin sections of the Banjari limestone he has also discovered (1949, Fig. 2) a slender verticillate structure with a globular head. This specimen is believed by Misra to represent some alga belonging to the Dasycladaceae.

A very interesting discovery of microfossils has been made by A. K. Ghosh and A. Bose (1950) in the olive shale belonging to the upper part of the Semri series of the Mirzapur district. The microfossils comprise carbonised fragments of wood with simple pits of variable size, wood with bordered pits, non-carbonised bordered-pitted elements with rays, and several monolet spores.

Bright coaly matter (vitrain) was discovered more than 20 years ago by C. S. Fox in the Bijaigarh shales (lower Kaimurs) of the Sone valley. Samples of the Bijaigarh shale containing lenticles of vitrain are reported to have been collected from the Vindhyan scarps west of the quarries of the Portland Cement Company of

Japla. The vitrain on analysis yielded 65.62% of fixed carbon; however it showed no vegetable structure and the lenticles were 'quite unrecognisable from the palaeontological point of view' (Auden, 1933, p. 182). Unfortunately, no sample of this Vindhyan coal is now available for examination by the palaeobotanical techniques. In March, 1951, we made a careful search for its occurrences in the Vindhyan scarps at Banjari and Baulia, the latter being the place where the quarries of the Portland Cement Company are situated. The search, however, proved fruitless. In a letter dated the 10th October, 1951, the late Dr. Fox informed one of us that the coal was found in very small amounts. Only 5 gm. of it was extracted with difficulty from several pounds of shale taken to Calcutta (see Fox, 1931, p. 26). Dr. Jacob of the Geological Survey of India (1949, pp. 202-203) has reported the occurrence of 'fairly large pieces of fossil wood' in ferruginous sandstones collected by G. V. Rao from the top of a hill near Gugri in Maihar, (entral India. The sandstones are believed to belong to the Upper Bhandar series. According to Jacob thin section of the wood did not reveal any clear structure; but in preparations of the woody elements teased out in clove oil bordered pits were clearly visible. The same preparations contained some spores with tri-radiate marks. These discoveries, in the words of Jacob, would be of outstanding importance were it not for the doubt attached to the provenance of the samples collected by Rao. Jacob suspects that the samples may have come from younger strata overlying the Vindhyan system at Gugri.

PRESENT INVESTIGATION

1. *Material and Methods.*

Except for the scattered records mentioned above no attempt at a systematic search for fossils in the Vindhyan rocks had been made when our work started. Moreover, it is only of late that microfossils have been included in the search. The present investigation cannot claim to be an exhaustive one, but we have examined rock samples from all the four main sub-divisions of the Vindhyan, viz. the Semri, Kaimur, Rewah and the Bhandar series (see list below).

Samples.	Horizon.
25/920, 25/921 ..	Sirbu shales (Bhandar series).
25/911	Jhiri shales (Rewah series).
45/310, 45/312	Panna-Jhiri shales (Rewah series).
*21/410, * 21/411, * 36/230	Suket shales (Kaimur series).
1358, 1986	Rohtas stage (Semri series).
4074, 4921, 4973, 4986, 7523	Kheinjua stage (Semri series).

The above samples and a shale numbered 36/198 (from the lower Vindhyan, exact horizon not known) were supplied by the Geological Survey of India. The samples listed below were collected by the authors from the Vindhyan of the Sone valley (March, 1951) and of Central India (February, 1952).

Samples.	Horizon.
Black thinly laminated shale from Jamunapani near Banjari (Dehri-Rohtas Light Railway).	? Bijaigarh shales (Kaimur series).
Black papery shale from a gorge west of the quarries of the Portland Cement Co. at Baulia.	

* These samples were examined by Messrs. D. C. Bhardwaj and R. N. Lakhanpal.

Samples.	Horizon.
Dark-coloured shales from (1) nala, cutting behind Chauki village, 4 miles from Rampura; (2) culvert of the Tilsoi river, about 1/2 mile from Rampura dak bungalow.	Suket shales.
Limestone from the quarries at Banjari.	
	Rohtas stage.

Two methods of investigation were employed: (1) maceration, and (2) preparation of thinly-ground sections for microscopic examination. The maceration was generally carried out in commercial nitric acid (of about 70% strength), Senftz's mixture (nitric acid + potassium chlorate), hydrochloric acid, or hydrofluoric acid. The macerated shale was then treated with ammonium hydroxide. Both in the selection of the samples and in the operations carried out during maceration and mounting of the material on the slides, every precaution was taken to avoid external contamination. The ground sections were made in every case both along and across the bedding plane of the rock. The sections as well as the macerated material were examined unstained. Fifteen to twenty slides were prepared from the macerated material of each sample.

B. Description of the microfossils.

Of the twenty samples examined only two, namely the Sirbu shale (25/921) and the Suket shale collected by us from the vicinity of Rampura have yielded microfossils. The Geological Survey of India gives the locality of sample 25/921 as 'just east of Saia, 12 miles West of Bhilsa', Central India.

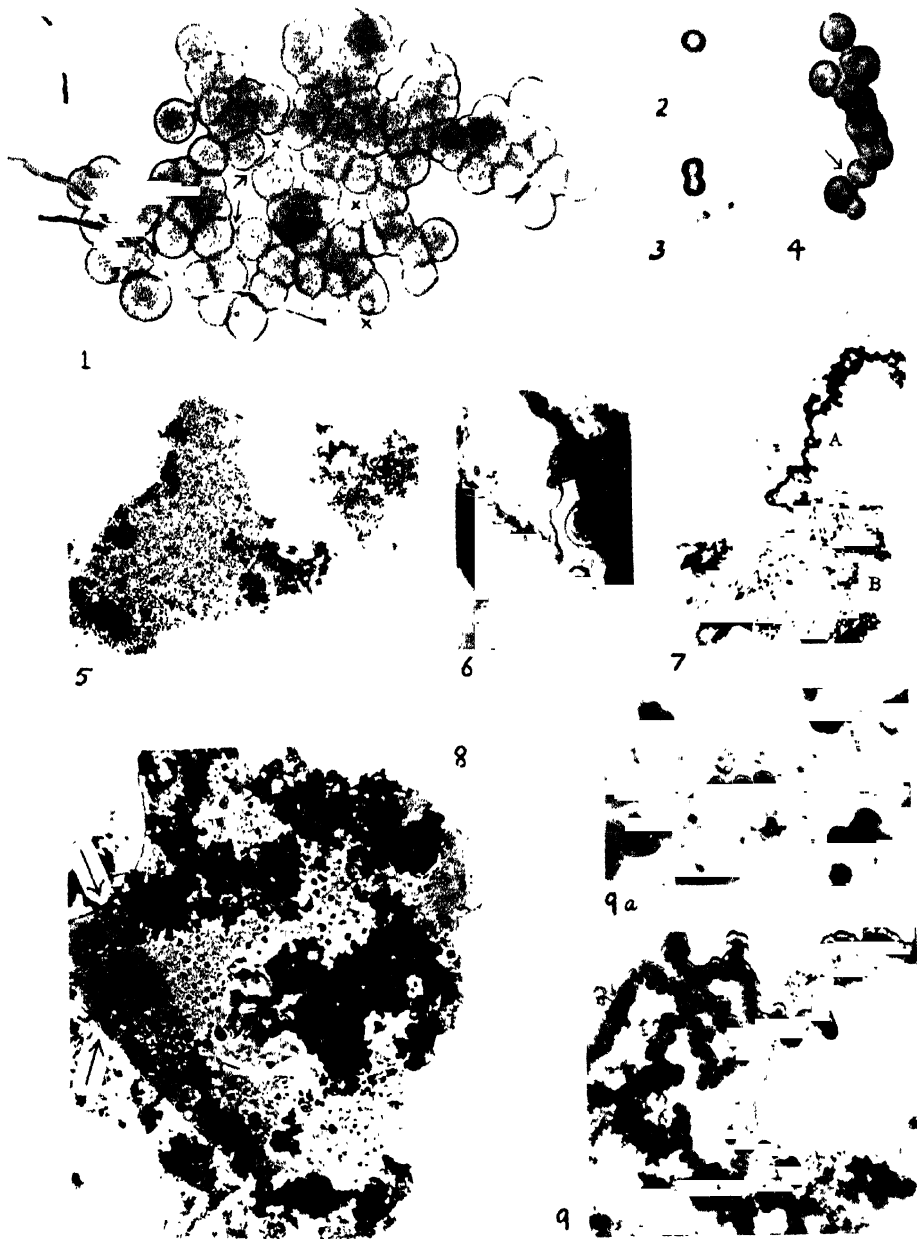
Algal remains.

(i) ? *Cyanophyceae*.—The algal remains shown in Figs. 1–5, 7–9 and 9a were obtained by maceration of samples of the Sirbu and the Suket shales in commercial nitric acid for about fifteen days followed by treatment with ammonium hydroxide for 2–3 hours. After the removal of the gross mineral particles the macerated material was mounted in glycerine jelly and in Canada balsam.

The specimens occur abundantly in the slides. The individual cells are spherical. Their size is variable, the most common diameters being 2μ , 3.5μ and 7μ . Single cells are met with but they are much more frequently seen in colonies of two or more closely aggregated individuals (Figs. 2–4). The aggregations occur in two forms: (i) a thin tabular colony formed of closely packed cells, which under the low magnifications of the microscope superficially looks like a piece of membrane (Figs. 5, 8); and (ii) a complex of more or less branched threads (Figs. 7A, 9).

Most of the tabular colonies show the form of the individual cell clearly under the higher powers of the microscope (Fig. 1). The cell-sheath must have been mucilaginous from the way the cells are seen held together. The cells in a colony either retain their spherical shape or get flattened by the pressure of their neighbours, in this way frequently presenting a polygonal outline in surface view. Sometimes the cells appear not to be in direct contact but connected by a narrow isthmus (Figs. 1 and 4, see near arrows).

In the second or the 'dendritic' type of the colony the form of the cells is generally not well preserved. This is also the case in some of the tabular colonies. The condition seems to have resulted either from the diffident nature of the cell-sheaths or from bad preservation. In some cases the obliteration of the cell walls has proceeded to the extent of making a part or whole of the colony look like a flat structureless membrane (Fig. 8, near arrows). In fact, were it not for the presence

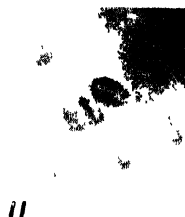




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12



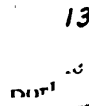
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25

in the slides of transitional stages (Fig. 10) it would be impossible to identify the structureless fragments with the ones showing cell outlines.

A peculiar feature seen in many of the cells is a rounded protuberance (Fig. 1 near XX). The protuberances show a variation in size which conveys the impression of growth. The phenomenon may be likened to the budding of the cells of yeast, but it is difficult to say whether the outgrowths in the fossils have resulted from a process of abstriction.

The cells of the 'dendritic' forms are similar to those forming the flat colonies. The cells do not aggregate to form threads of uniform thickness but give rise to numerous bulges and short, blunt branch-like outgrowths. The threads themselves curve and loop variously. There are many specimens (Fig. 7B) which show a condition intermediate between that of the colonies in Figs. 9 and 5. The 'dendritic' forms thus most probably represent early stage which later on grew into sheet-like expansions of the alga.

In a vertical section the colonies may be single layered or in places show more than one layer of cells. Areas of more than one layer of cells, however, are never extensive. They can be distinguished in surface view as patches of darker colour.

Apart from the macerated material the colonies have also been met with in a thin section of the Sirbu shale (25/921). This section (Fig. 6) along the bedding plane of the shale shows a few spherical cells of a colony, very similar to those discovered in the macerated material. Although the preservation of the cells in the section is not good the resemblance in form, size, and colour between these and the ones shown in Figs. 1-4 is striking.

Affinities.—The nearest comparison of these fossils is with the Cyanophyceae. The single cells as well as the colonial forms are very suggestive of the habit of some of the palmelloid types of the Chroococcales (cf. Fritsch, 1945, Fig. 304 1, J.). There is no evidence of a common mucilage envelope in the Vindhyan fossils. Cell division was probably the chief method of multiplication by which an extensive prostrate system was developed. But the rather frequent occurrence of rounded protuberances in the cells is a feature of interest here. This is an uncommon phenomenon among the blue-green algae. In *Rosaria ramosa*, a New Caledonian genus of the Stigonematales Carter (1922, Pl. 4, Figs. 2-6) has recorded growth by the budding of the apical cells; but there is no other similarity between this alga and the fossils. The living species has a characteristic habit of long slender filaments only one cell in width. Budding was perhaps an accessory mode of multiplication in the fossil forms. The Vindhyan specimens probably represent a primitive group of algae closely related if not belonging to the Cyanophyceae.

The microfossils described below were obtained from the Sirbu shale (25/921) by macerating it in hydrofluoric acid. The slides were mounted in Canada balsam and glycerine jelly.

(ii) *Fusiform bodies.*—A large number of these peculiar barrel shaped bodies have been met with in the slides. The individuals are on the whole fusiform in shape (Figs. 16-17, 19-21). The ends are flattened but in some of the specimens they are seen broken into a number of finger-like projections (Fig. 16). In several cases the body is seen divided along the shorter axis into two symmetrical halves, the line of division often coinciding with a slight constriction of the sides (Figs. 16-17, 21). The specimens measure up to $38\ \mu$ along the longer axis and $17.5\ \mu$ along the shorter. Fig. 18 shows two specimens seemingly joined end to end.

It is difficult to determine the relationship of these fossils. The shape is suggestive of desmids, especially in the case of the specimens where the division of the body into two halves is seen. The modern Desmidioidae with the exception of one species are restricted to fresh waters.

(iii) *Round bodies*.—These are thin walled and somewhat flattened (Figs. 14–15). They are present in different sizes (the average specimens measure 31μ in diameter) but all of them are very much larger in diameter than the cells of colony shown in Fig. 1. No colonial forms of these have been discovered. It is possible that they represent some unicellular algae.

(iv) *Disc-like forms*.—Fig. 23–24 show disc-like forms 105μ in diameter. The surface is cracked, but the circular outline of the specimen is clear. An interesting feature of the specimens is the presence of a fine concentric striation along the periphery (Fig. 25) somewhat similar to the 'growth lines' described in *Fermoria*. Walcott (1919) has figured plant masses of blue-green algae such as *Nostoc* and *Anabaena* flattened and dried on card. These often take the form of circular discs of different sizes. It is possible that the Vindhyan specimens also represent similar plant masses flattened by fossilisation.

Fungal spores.

Small oval spores probably of fungi (Fig. 11–13) have been discovered in thin sections of the Sirbu shale (25/921). They measure 2.5μ – 3.5μ along their longer axis. In some cases a curved mark is seen on the spore. This probably represents a fold in the spore wall.

Filamentous body.

Another thin section of the same shale contains a septate filament (Fig. 22) with thin and rather shrunken walls and tapering ends. The cells measure 5 – 7μ in width in the middle of the filament.

C. Mode of preservation of the specimens.

So far form is a guide the specimens just described appear to be plant structures. There is no evidence to show that any part of the original plant matter is preserved in the fossils. They are probably mineral casts formed of a reddish or brownish translucent substance which surprisingly resists mineral acids like nitric and hydrofluoric acids. When examined in polarised light all the specimens shown in the plates are isotropic under crossed nicols, and with the polariser alone no pleochroism is seen.

Owing to the minute size of the specimens tests for determining their chemical composition have not been practicable. It has, however, been possible to apply the test of incineration in one case, viz. to the colonies recovered from the Suket shale (Fig. 9a). A number of such colonies were subjected to red heat in a platinum crucible. The fact that they did not burn shows that they are mineral casts.

The case of *Fermoria* forms an interesting parallel. Here there is an external coaly layer covering a subtranslucent foundation. The inner layer consists of angular flakes of pale horn-brown colour which are isotropic under crossed nicols (Chapman, *loc. cit.*, p. 111). We think this inner layer possibly represents a mineral infilling similar to that which has formed the casts in the present microfossils. This is supported by the test of incineration which we have applied to several specimens of *Fermoria* collected recently from the vicinity of Rampura. Even after the application of red heat for several minutes the flaky layer did not disappear.

In the case of the present fossils only the mineral cast has been left. The original plant matter was probably not preserved. But if it did leave a carbonaceous film like the layer of carbonised organic matter in *Fermoria*, it

must have been of a very fragile nature. Such carbonaceous films can be easily destroyed by the action of macerating fluids.

THE AGE OF THE VINDHYANS IN THE LIGHT OF PLANT FOSSIL EVIDENCE.

Except the groups of small oval spores (Figs. 11-13), which are probably fungal, and the filamentous body shown in Fig. 22, the plant remains described above seem to be algal in nature. Among these the affinities of the fusiform bodies (Figs. 16-21) and the rounded bodies (Figs. 14, 15) are not known. The microfossils shown in Figs. 1-10 indicate a strong affinity with the Cyanophyceae. This is an ancient group which has persisted with little alteration during long epochs of the earth's history (Fritsch, 1945, p. 768). Representatives of the blue-green algae are known from the Cambrian period onwards and the group is even believed to extend to the pre-Cambrian times. The only other algal remains described from the Vindhyan are by Misra (1949) and Misra and Bhatnagar (1950). These authors have described an alga belonging to the Dasycladaceae and minute spherical bodies which they compare with 'algal dust'. Fossil forms of the Dasycladaceae are known from the Ordovician onwards.

Taken as a whole, the algal remains so far discovered are not in conflict with an early Palaeozoic age ascribed to the system on the basis of stratigraphical data. As there is little doubt regarding the organic nature of these discoveries, we can safely agree with Wadia (1939, p. 101) and Reed (1947, p. 420) that at least a part of the Vindhyan system should be included within the Cambrian. The algal remains mentioned above do not provide sufficient ground for lifting the Vindhyan to a horizon younger than this.

We find it too early to express an opinion on the vascular flora described by A. K. Ghosh and A. Bose (1950) from the Vindhyan. The discovery is of very great interest, involving, as it does, questions of fundamental importance both to botany and geology. For the elucidation of these we must await further data.

Postscript.—Since the manuscript of this paper was submitted to the press we have received a copy of a note in *Nature* by A. K. Ghosh and A. Bose (1952) describing spores and tracheids from a shale of Upper to Middle Cambrian age in Kashmir. This shale contains, apart from the microflora now described, *Tonkinella* and *Obolus*-like brachiopods. Ghosh and Bose (*loc. cit.*) remark: 'These data obtained in India as well as those recorded in the Swedish "Kolm" and the U.S.S.R. all taken together tend to suggest an earlier phylogeny of vascular plants, going back to the Cambrian period and not the Silurian-Devonian period as generally supposed.' As time passes, perhaps more data of similar nature will become available from strata of pre-Cambrian or Cambrian age. Till we have data sufficient to be convincing, the question of the origin of vascular plants as early as the Cambrian must, in our opinion, remain *sub judice*.

SUMMARY.

Microfossils assumed to be algal and fungal remains are described from the Suket and the Sirbu shales. The previous records of life in the Vindhyan strata are reviewed. The sum total of the evidence of the plant remains supports the view that the Vindhyan are of an early Palaeozoic (Cambrian) age.

ACKNOWLEDGEMENTS.

We are thankful to Professor O. A. Höeg, Dr. R. C. Misra and Mr. B. N. Prasad for helpful suggestions and specially to Dr. R. C. Misra for his opinion on the optical behaviour of the fossil specimens.

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EXPLANATION OF PLATES.

(All the photographs are untouched.)

PLATE III.

- 1-9. ? Cyanophyceae.
1. A typical unbranched colony. $\times 1445$.
 2. A single cell. $\times 906$.
 3. A two-celled colony. $\times 906$.
 4. Another colony containing about a dozen cells. $\times 1230$.
 5. A colony under low magnification. The close aggregation of the cells forms sheet-like expanses. $\times 90$.
 6. An aggregation of a few cells observed in a thin section of the Vindhyan shale. $\times 916$.
 7. Another colony under low magnification. A, a branched form. B, a sheet-like structure with cells more loosely packed than in fig. 5. $\times 90$.
 8. One of the sheet-like structures. The cell outlines are not everywhere distinct. The portion to which the arrows point shows a complete obliteration of the cells, giving the appearance of a structureless membrane. $\times 221$.
 9. A typical branched colony. $\times 373$.
 - 9a. Another branched colony (Suket shales). $\times 1445$.

PLATE IV.

10. ? Cyanophyceae: A part of specimen in fig. 8 (near top right hand corner) enlarged to show the form of the cells which in other parts of the specimens have become obliterated. $\times 896$.
- 11-13. Groups of fungal spores observed in a thin section of the Vindhyan shale. 11, $\times 1761$; 12, $\times 1619$; 13, $\times 996$.
- 14-15. Rounded bodies (probably unicellular algae). $\times 414$.
- 16-21. Fusiform Desmid-like bodies. Fig. 18 shows two specimens joined end to end. $\times 679$.
22. A filamentous body observed in a thin section of the Vindhyan shale. $\times 1059$.
- 23-24. Disc-like forms. The cracks in the peripheral region are due to the pressure of the coverglass on the specimen. $\times 62$.
25. A portion of the specimen in fig. 24 further enlarged. The surface near the periphery shows concentric striation. $\times 174$.

ON SOME CONIFEROUS CONES, PROBABLY OF *BRACHYPHYLLUM*, FROM THE JURASSIC OF THE RAJMAHAL HILLS, BIHAR, INDIA,

by M. N. BOSE and J. HSÜ, *Birbal Sahni Institute of Palaeobotany, Lucknow.*

(Communicated by Prof. S. R. N. Rao, F.N.I.)

(Received June 20; after revision, September 2; read October 4, 1952.)

INTRODUCTION.

During the last two excursions in 1948 and 1950 we collected some plant fossils from a ferruginous oolite of Jurassic age in Amarjola in the Amrapara district, Bihar. Of these fossils some leafy branches referred to the genus *Brachyphyllum* have already been studied by one of us (Bose). In continuation with that we examined some detached coniferous cones, which were considered most probably to belong to the same genus. These are poorly preserved and are rather crumbly. With the aid of strong light and under immersion in xylol we were able to examine the surface of the outer epidermis of the cone scales. After boiling in Canada balsam these cones could easily be cut and ground into thin sections. Thus we were able to study, besides the external morphology, the internal anatomy also, which was so far very little known.

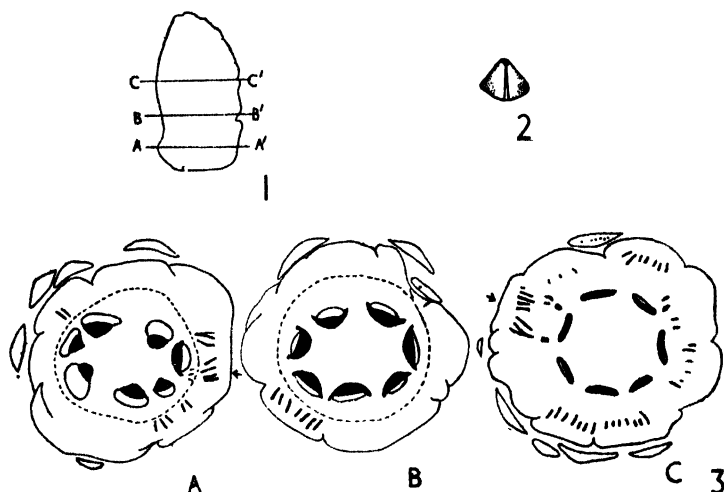
DESCRIPTION.

External appearance of the cone.—The figures 1 and 2 in Pl. V represent some ellipsoidal cones which measure about 2 cm. in length and 1.3 cm. in diameter. They appear to be sessile and are covered with crowded, imbricate, small scales which are spirally arranged. In passing around the middle part of the cones, 9–11 scales are met with. They look rhomboid but are really triangular in shape, because some part of the leaf base is covered by the two neighbouring scales. The scales are 3 mm. long and 3 mm. wide in average, and have a prominent median dorsal keel and an obtuse, slightly out-turned apex (text-fig. 2). Because of bad preservation most of apex of the scales have already been lost and only some rhomboid cushions of the leaf bases are left on the cone axis (Pl. V, fig. 1).

General Morphology and Anatomy of the Cones.—Pl. V, fig. 3, represents one of the longitudinal sections of the cone made from the one shown in Pl. V, fig. 1. The cone consists of a thick axis, covered by some small scales (s). In these sections the fertile organs are only represented by some disorganised tissues found in the two flanks, left and right of the tip of the cones in which hundreds of pollen grains (p) are enclosed. These pollen grains are grouped in masses and thus considered definitely belonging to the cone. Accompanied with these, a few elliptical bodies are present which are rather suggestive of pollen sacs. But due to bad preservation they are much crumbled and therefore no detailed description can be given. Under these elliptical bodies some tracheids have been found which may have supplied the male organs. Furthermore we carefully examined a series of transverse sections (text-figs. 3A–C) cut from the base to near the tip of the cone figured in Pl. V, fig. 2, and found no fertile organs elsewhere. Thus so far the present cones are concerned the microsporophylls may have arisen only from the terminal or subterminal region of the cones. As there is no indication of female organs in these cones, we may safely say that our cones most probably are unisexual.

Epidermal structure of the cone-scales.—Owing to bad preservation, we could not obtain any cuticle from the cone scales by maceration. However, examining the cone figured in Pl. V, fig. 1, under microscope, we found that the epidermis on the abaxial surface of the cone scales is composed of mainly 4–7 sided isodiametric cells, about 50–70 μ in diameter (text-figs. 9 and 10) which do not form any regular rows. The anticlinal walls of these cells are almost straight and become slightly thicker at the corners of the cells. No stomata have been observed.

Anatomy of the Cone-axis.—Text-figs. 3A–C represent the diagrams traced from photographs of three successive cross-sections cut between the base and the part just below the tip of the cone figured in Pl. V, fig. 2. The three approximate planes of the sections are indicated in text-fig. 1, by the lines AA' BB' and CC'. In these cross-sections a massive pith is seen which is surrounded by a ring of 7 vascular bundles, a thick cortex, and the bases of cone scales. A longitudinal section of the same is shown in Pl. V, fig. 3.

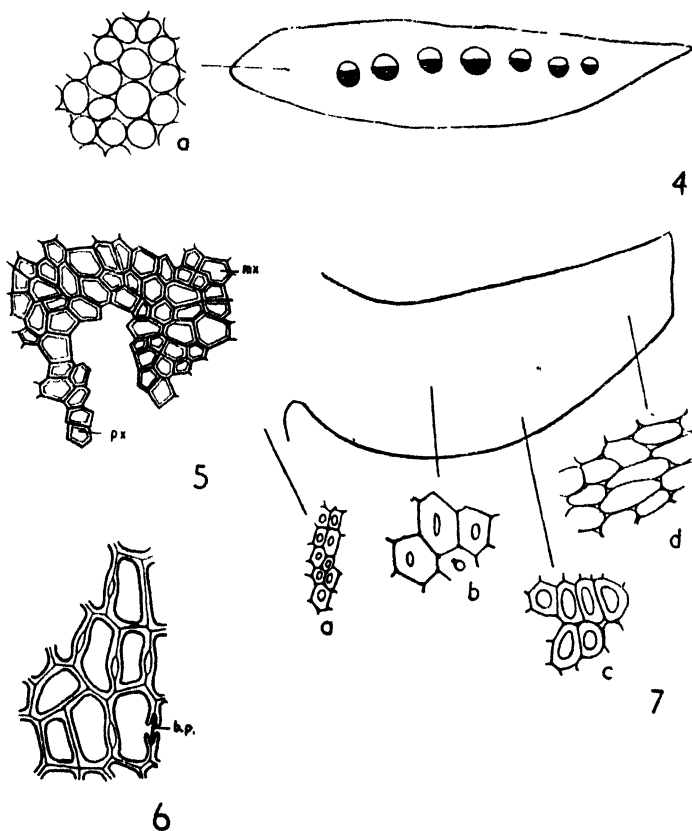


TEXT-FIG. 1. Diagram of the cone, shown in Pl. V, fig. 2. The lines AA', BB' and CC' indicate the levels at which cross sections were made. ($\times 1$).
 „ 2. Sketch of a cone scale, showing the out-turn apex and the median dorsal keel. ($\times 2$).
 „ 3. Diagram traced from photographs representing vascular structure of cone axis as seen in a series of cross-sections A, B, and C from base to the level near the apex, indicated by lines AA', BB' and CC' in text-figure 1. Origin and course of the vascular supply of some cone.

In structure the pith is quite uniform. It consists mainly of parenchymatous cells which are more or less isodiametric and 4–7 sided in cross-section and slightly elongated in longitudinal section (text-figs. 11 and 12). Neither resin canals nor secretory cells are seen. But occasionally in the peripheral region of the pith, near the scale bases, some small stone cells are observed (text-fig. 7a). These cells are grouped in vertical rows, about 10 or more cells in length and about 2–3 cells across, running parallel to the surface.

At the base of the cone the vascular strands are seven in number and triangular to elliptical in cross-sections. A few of them seem to have been united but now become separate from each other. They are collateral, with a considerable amount of xylem and phloem. Most of them are secondary in nature, intercalated with uniseriate ray cells. At this level the phloem forms a broad concave arc, with its two flanks almost touching, left or right, its neighbouring bundles. But in the section shown in text-fig. 3A cut at the level slightly above the base of the cone the

bundles look thicker and are arranged at a distance from one another. The tracheids of the secondary xylem (X^2), being densely arranged, are squarish in cross-section (Pl. VI, fig. 9). It appears that only the radial walls of the tracheids have developed uniseriate bordered pits (Pl. VI, fig. 11 and text-fig. 6) *b.p.* The longitudinal sections show that the tracheids of the bundles in this region are mainly pitted but some of them which are better preserved show both bordered pits (*b.p.*) and spiral bands (*s.b.*) (Pl. VI, fig. 12). At slightly higher level (text-fig. 3B) the



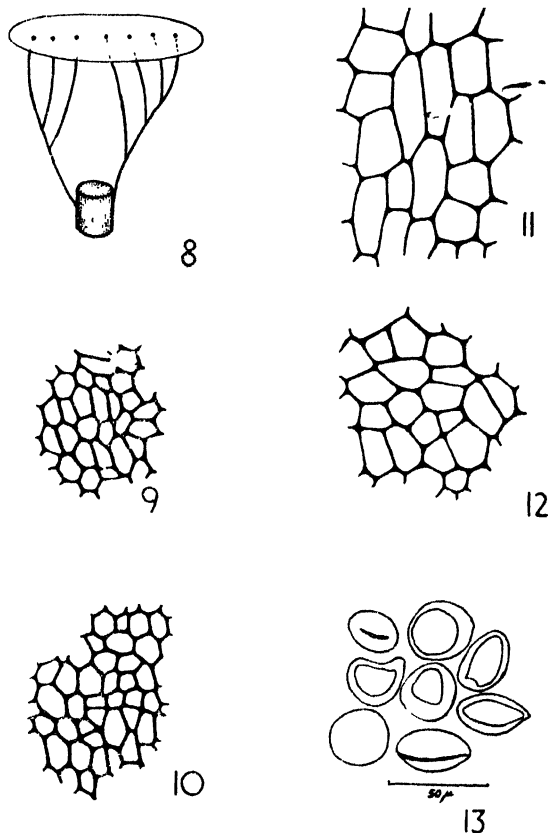
- TEXT-FIG. 4. Diagram of cross section of a cone scale showing seven vascular bundles; 4a. Cross section of part of a cone scale showing cells of ground tissue. 4 ($\times 25$), 4a ($\times 135$).
 „ 5. Cross section of a part of vascular strand shown in text-fig. 3C. *px*, protoxylem and *mx*, metaxylem. $\times 270$.
 „ 6. Cross section of a part of the secondary xylem shown in Pl. VI, fig. 11. *b.p.*, bordered pit. $\times 540$.
 „ 7. Sketch of a cone scale in longitudinal section indicating the location of the following tissues:
 (a) Group of small stone cells. (b) some large stone cells. (c) collenchymatous cells, and (d) cells of the ground tissue. $\times 135$.

vascular bundles become elongate and in the section cut near the tip, vascular strands are transformed into thin arcs, with their concavity towards the outer surface (text-fig. 3C; Pl. VI, fig. 8). These bundles are primary in nature. As seen in longitudinal sections these bundles are composed of only spiral and finely scalariform tracheids which at some place, near the tip of the cones, disappear altogether. The bundles are collateral and endarch. A row of protoxylem group (*px*) is shown

in part in text-fig. 5 where there is no metaxylem (*mx*) developed on the centripetal side.

The phloem (Pl. VI, fig. 9, *ph*) is not well preserved but it is marked by some layers of heavy-walled elements alternating with thinner walled ones with regularity in the tangential direction.

Pericycle is not clearly seen in these specimens, but the cortex is well developed; it consists of small parenchymatous cells. In the inner cortex (*i.c.*) these cells are roundish in cross-section, with well-developed intercellular spaces (Pl. VI, fig. 8), while those in the outer cortex (*o.c.*) are rather densely arranged and squarish in cross-section (Pl. VI, fig. 7).



TEXT-FIG. 8. Diagram showing the origin and course of vascular supply of the cone scales.
 „ 9 & 10. Outer epidermal cells of the terminal and the basal parts of a cone scale. $\times 60$.
 „ 11 & 12. Longitudinal and cross-sections of pith cells. $\times 135$.
 „ 13. Sections of pollen grains. $\times 270$.

The cortical cells (*c.s.*) near the scale base (Pl. VI, fig. 7) are similar to those of the outer cortex, except that they are very much flattened.

In all specimens the epidermis is not well preserved.

Anatomy of Cone-scales.—The cone-scales are rather simple in structure. Two to three layers of hypodermal cells are visible under the epidermis (text-fig. 7c) but these cells are more developed at the margin of the scales. The mesophyll is composed mainly of round to ellipsoidal parenchymatous cells (text-figs. 4a and 7d) which show no clear differentiation into palisade and spongy tissues. At the base

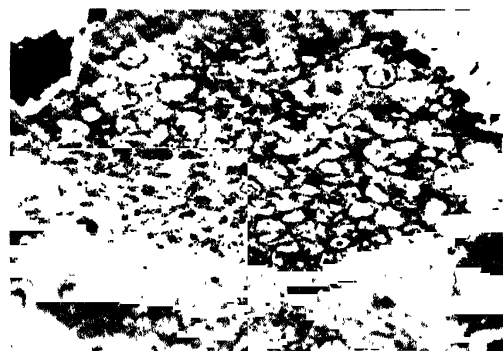




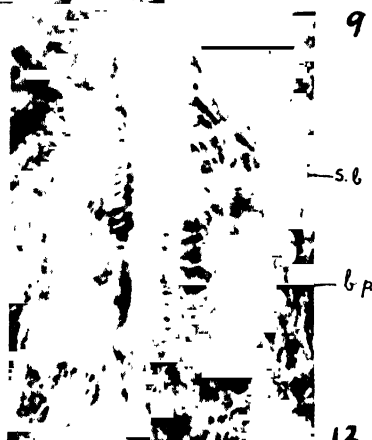
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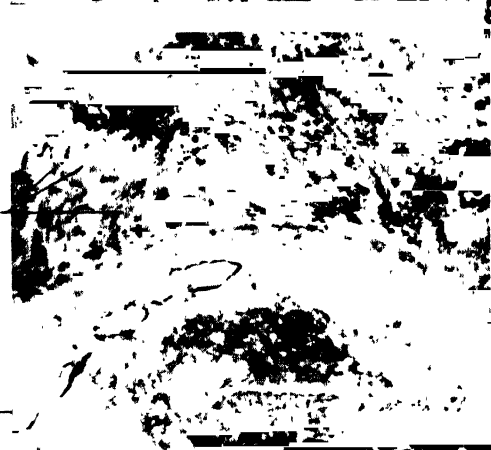
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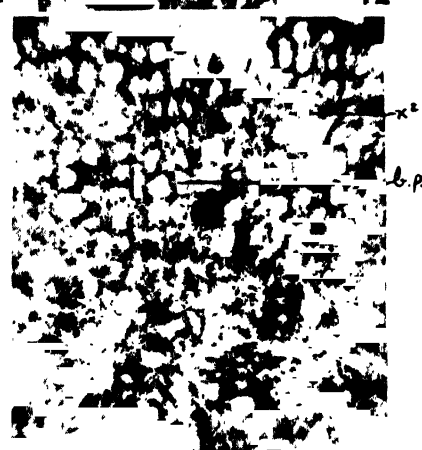
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10



11



12

of the scales, these cells are more densely arranged and squarish in cross-section, but higher up they become rather loose with well-developed intercellular spaces. Here and there a few stone cells (Pl. VI, fig. 4 and text-fig. 7b, s.c.) are found intercalated among the mesophyll cells. No resin canals are seen. These scales are somewhat fleshy in nature. The same structure is seen in the longitudinal sections. In Pl. VI, fig. 4, the ground tissue is unfortunately completely hidden by some cracks in the matrix which give a false impressions of pattern of cells.

The vascular bundles are parallel and about 7 in number at the base of the scales (text-fig. 4). These bundles also appear to be collateral and they are not enclosed by any kind of thick-walled cells. In longitudinal sections they show only spiral and finely scalariform tracheids. Pl. VI, fig. 5, shows a cross-section of a scale cut just above its midriff region, where only ground tissue is seen, without any sign of vascular bundles.

Origin and course of the vascular bundles of the cone-scales.—The vascular bundles which supply the scales are given off from both the free ends of the bundles of the cone axis (Pl. VI, fig. 10; text-fig. 3A). Tracheids in these bundles are rather short. Their walls appear to have reticulate thickenings. As the preservation is not very satisfactory, it is very difficult to say whether these tracheids are really transfusion tissues of the type usually found in the same position on the two flanks of xylem strand in the scale leaves of some recent conifers such as *Juniperus*, etc. (Hsü, 1935).

The bundles first go outwards almost at a right angle to the cone axis and each soon divides into two small branches. As the branches pass outwards and upwards through the cortex, they lose their secondary tissues (Pl. VI, fig. 10) and divide once more to form seven (rarely eight) small bundles; three are found on one side, and four (occasionally five) come from the other, as in the parts indicated by an arrow in the text-figs. 3A, 3C. They run parallel to one another into the scale and are dying out when they travel about half the distance of whole length in it.

Pollen grains.—The pollen grains are very small, round to ellipsoidal about $30\ \mu$ in diameter, or $30 \times 35\ \mu$ to $25 \times 40\ \mu$, with thick and smooth wall (text-fig. 13). Neither a slit, nor a wing is seen in a pollen grain. Some of them have elongated or irregular folds which are due to preservation.

COMPARISON, DISCUSSION AND CONCLUSION.

Cones of this type have once been recorded in India from the Jurassic of Vemavaram of the Kota stage by Professor Sahni (1928, p. 37; Pl. VI, fig. 80) who named them *Conites*. These fossils are preserved only as casts, but look very much like ours in their external appearance. Therefore it is likely that they are identical. When we compare our cones with the leafy shoots of *Brachyphyllum* collected by one of us (Bose) from the same bed, we find that the form and arrangement of the rhomboid scales in our cones also have a very great resemblance to those of the leafy shoots of *Brachyphyllum* sp. The description of these shoots is going to be published separately by Bose. Each of these scales have a prominent median dorsal keel and an obtuse out-turned apex just like those of the leafy shoots. The cells of the epidermis of the abaxial surface of the cone scales also show a close resemblance to those of the epidermis of the same surface of the scale leaves. But the difference is that the epidermal cells of the present specimens are slightly bigger in size, otherwise they are almost identical.

In comparing their internal structure, the pith and the cortex of both the cone axis and of the stem are composed mainly of parenchymatous cells, except that some stone cells are present in the outer region of the pith of the cone axis only. In general, the cone axis shows less development of secondary xylem than that of the stem. In both cases the secondary wood is compact with small tracheids and uniseriate rays and only on the radial walls of the tracheids, uniseriate bordered pits

are developed. The spiral bands found on the walls of the secondary tracheids of the present cones are again very much similar to those of the stem of *Brachyphyllum* sp. Therefore the present cones probably belong to a species of *Brachyphyllum*.

We have already mentioned that except some groups of small pollen grains found in the terminal region of the cones, no fertile organs have so far been observed. This fact indicates that the microsporophylls may have only arisen at the terminal or sub-terminal region of the cones. If so, it would recall those of the male cones of the modern *Taxus* (Zimmermann, 1930, p. 232, fig. 160A).

Unfortunately our investigation is limited due to lack of sufficient specimens. Though we know the importance of the location of microsporophylls in the male cones of conifers, yet it is no use to discuss this problem without sufficient facts regarding these cones in front of us.

Furthermore, Miss Kendall (1949, pp. 160-1; fig. 4A-E) described some male cones of *B. mamillare* Brongn. from the Middle Jurassic of Yorkshire. In her figure 3C, she showed some microsporophyll stalks arising from the middle part of the cones, and in her figure 3B, a part of the cuticle obtained from the tip of one of these microsporophylls has been given. If so, the microsporophylls can also arise from the middle region of the cones of *Brachyphyllum*.

In comparing the pollen grains of our cones with those of *Brachyphyllum mamillare* described by Kendall (1949, p. 161), they are quite similar, except that ours are variable in form and not always round. In size, the pollen grains of *B. mamillare* are 60-80 μ in diameter, while ours are about 30 μ .

So far the occurrence of spiral bands on the walls of secondary tracheids is concerned, our cones share the character with the modern *Taxus*.

Miss Kendall (1949) thinks that *Brachyphyllum mamillare* Brong. is a member of the Araucariaceae, but in our opinion as a whole *Brachyphyllum* may be still considered as a form genus. Since we have been able to obtain some information about it through the Indian fossils, we may expect a better result if further investigations are carried out.

ABSTRACT

This paper describes some coniferous male cones collected from Amarjola in the Amrapara district, Bihar. These cones are ellipsoidal in form, covered by crowded, imbricate, small, rhomboid, spirally arranged scales. Each of them has a prominent median dorsal keel.

The outer epidermis of the cone-scales is composed mainly of isodiametric cells which do not form any regular rows.

The cone axis possesses a large pith, surrounded by a ring of seven vascular bundles and a thick cortex. The cells of pith are mainly parenchymatous. The vascular bundles are collateral and endarch, with secondary tracheids having both bordered pits and spiral bands.

The main part of the scales is composed of ground tissue. Therefore it appears fleshy in nature. Under the epidermis 2-3 layers of hypodermal cells and at the base of the scales, seven parallel vascular strands are seen. These strands arise from free ends of the bundles of the stele, but divide rapidly into seven small bundles passing into the scales and die out when they travel about half the length in the scales.

Pollen grains are small, round or ellipsoidal and are found in groups only at the terminal region of the cones enclosed by some disorganised tissues of probably microsporangia and microsporophylls.

Comparing the external morphology of the cones, the outer epidermal characters of the cone scales and the internal structure of the cones, with those of the leafy shoots of *Brachyphyllum* which are found in the same locality, it appears that these cones belong most probably to the same genus.

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EXPLANATION OF PLATES.

PLATE V.

- FIG. 1. A cone. ($\times 8$)
 „ 2. Another cone. ($\times 8$)
 „ 3. Longitudinal section of the cone, shown in fig. 1, *s*, cone scale; *p*, pollen grains. ($\times 5.6$)
 „ 4. Longitudinal section of a cone scale; *s.c.*, stone cells. ($\times 51$)
 „ 5. Cross-section of a cone scale cut just at the level above its middle region. ($\times 51$)
 „ 6. Cross-section of the outer part of a cone near the scale base, showing seven vascular bundles running from the cone axis into a cone scale. ($\times 21$)

PLATE VI.

- FIG. 7. Cross-section of the outer cortical region of a cone. *o.c.*, outer cortex; *c.s.* cortical cells near the scale base. ($\times 108$)
 „ 8. Cross-section of part of the central region of the cone, made at the level CC', indicated in text-fig. 1, showing vascular bundles (*v.b.*) containing only primary tissues; *i.e.*, inner cortex. ($\times 49$)
 „ 9. Cross-section of part of the central region of the cone made at the level BB' indicated in text-fig. 1, showing secondary xylem (*X²*) and phloem (*ph*) of the vascular bundles. ($\times 45$)
 „ 10. Cross-section of part of the central region of the cone made at the level AA', indicated in text-fig. 1, showing the course of scale traces (*s.t.*). ($\times 20$)
 „ 11. Cross-section of basal part of a cone, showing the tracheids of the secondary xylem (*X²*) with bordered pits (*b.p.*) developed on their radial walls. ($\times 207$)
 „ 12. Longitudinal section of the basal part of a cone, showing secondary tracheids of the vascular bundles, having both spiral bands (*s.b.*) and bordered pits (*b.p.*) developed on their radial walls. ($\times 497$)

Issued April 9, 1953

STUDIES ON THE ELECTROCHEMICAL PREPARATION OF SODIUM HYDROSULPHITE.

PART IV. ELECTROCHEMICAL PRODUCTION OF SOLID HYDROSULPHITE

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(Communicated by Dr. J. C. Ghosh, F.N.I.)

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In our previous publication (Patel and Rao, 1949) on the direct electrochemical preparation of sodium hydrosulphite by the reduction of bisulphite, the maximum concentration of hydrosulphite obtained in the cathode solution was 10.7%, which was much higher than that obtained by earlier workers (K. Jellinek and E. Jellinek, 1919). Attempts to raise this value, however, were unsuccessful owing to the decomposition of hydrosulphite at higher concentration. In order to prevent the decomposition of hydrosulphite, it was necessary to keep down the effective concentration of the sodium hydrosulphite in the catholyte. This could be effected by the precipitation of hydrosulphite (1) by the conversion of the hydrosulphite produced into an insoluble form like calcium hydrosulphite, and (2) by crystallisation as $\text{Na}_2\text{S}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$ by the addition of sodium chloride to take advantage of the common ion effect. When calcium chloride was added to the catholyte, the hydrosulphite was precipitated as its calcium salt and the total concentration of the hydrosulphite went beyond 13% on prolonged electrolysis. The precipitate was found to contain about 37% of calcium hydrosulphite, the rest being calcium sulphite. Although by this method one could succeed in getting a higher concentration of hydrosulphite, yet the contamination of the calcium hydrosulphite by the calcium sulphite was the main disadvantage. Hence, this method was not continued further.

On the other hand, when sodium chloride was added to the catholyte, preliminary experiments indicated that the total concentration of hydrosulphite went beyond 13%, precipitating at the same time pure sodium hydrosulphite in the catholyte. Hence, this method was investigated in detail.

EXPERIMENTAL.

The apparatus, used in the investigation for the electrochemical preparation of sodium hydrosulphite was essentially the same as that employed by the authors described in a previous publication (Patel and Rao, 1949). The following are the modifications (Fig. 1) effected in order to get a quantitative idea of the various products of reaction. (1) In the earlier work, the solution for analysis was directly drawn into the burette but this was not practicable in the present case due to the formation of the hydrosulphite slurry in the catholyte. The cathode slurry was therefore, pipetted out for analysis of hydrosulphite through an opening *H* which was normally kept closed by a glass rod. (2) The cathode chamber was provided with a fritted glass filter *F*, connected to the microburette *B*. The arrangement indicated in the diagram enabled one to remove the filtered catholyte for analysis by using suction. (3) An inlet for sulphur dioxide was also provided as shown in the figure. (4) The external surface of the porous diaphragm *D*, above the level of

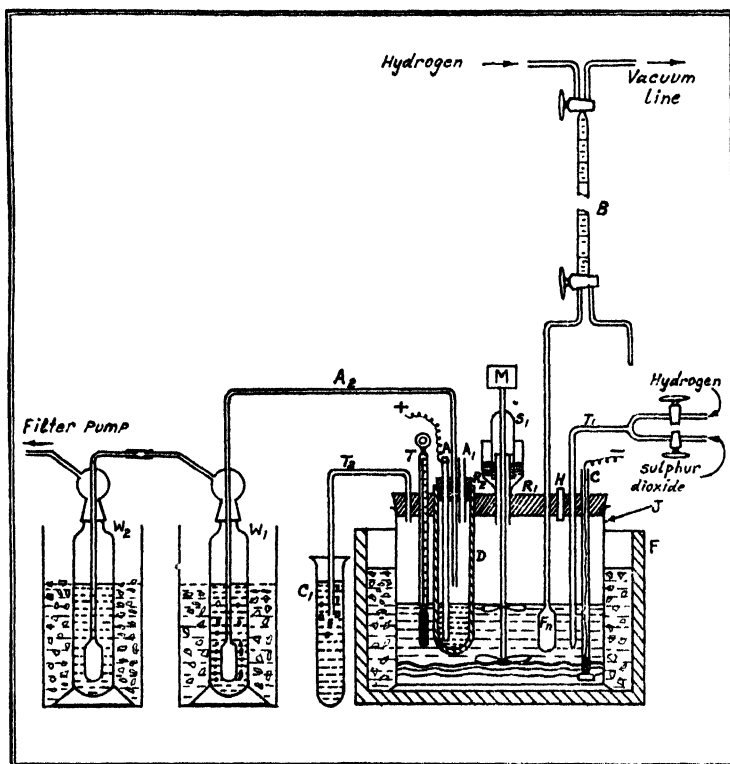


FIG. 1.— A_1 = Inlet tube for air, A_2 = outlet tube for gases, S_1 = mercury seal stirrer, J jar, F = water bath, T_1 = gas inlet tube, T_2 = exit gas tube, C_1 = water seal, C = connecting tube for mercury cathode, R_1 & R_2 = Rubber Stoppers.

the liquid, was coated with paraffin to prevent the escape of anode gases into the cathode compartment. The diaphragm, serving as anode chamber, was closed at the top with a paraffined rubber stopper R_2 provided with two glass tubes as in the figure. The gases produced in the anode chamber were swept into the gas washing bottles W_1 and W_2 containing caustic alkali. The anode A consisted of a graphite rod in place of a platinum electrode used in the earlier work.

MATERIALS EMPLOYED.

(1) *Sodium bisulphite solution*.—A stock solution of bisulphite was prepared in an inert atmosphere by passing sulphur dioxide through aqueous sodium carbonate (c.p.), employing an external indicator (methyl yellow screened with methylene blue) which turned pink at pH 4.3. The solution thus prepared was analysed for its bisulphite content and preserved under an inert atmosphere. The bisulphite solution was free from sulphate.

(2) Standard analytical solutions used in this investigation were generally prepared from chemicals of A.R. quality. The rest of the chemicals employed were of C.P. grade.

(3) *Sulphur dioxide*.—It was taken from a cylinder containing liquid sulphur dioxide and was found to be free from oxygen.

(4) *Hydrogen*.—It was electrolytically prepared and was freed from any oxygen by passing through alkaline pyrogallol.

added to it. The flask was shaken carefully and then heated on a water bath for about half an hour to complete the oxidation. The contents of the flask were cooled and made up to 100 ml. Aliquots were employed for the analysis of the chloride and the sulphate. The chloride was estimated volumetrically by Volhard's method and the sulphate gravimetrically as barium sulphate.

(e) *Estimation of total hydrosulphite produced during the electrolytic reduction.*

After the electrolysis, the current was switched off. The catholyte was made alkaline by addition of dilute ammonia and the hydrosulphite was completely brought into solution by addition of sufficient air-free water at 0°C. A sample was withdrawn and the hydrosulphite was determined by the cuprammonium sulphate method. The total volume of the diluted cathode solution was then measured. The total hydrosulphite produced could thus be computed with suitable corrections for the samples withdrawn at intervals for analysis and the overall current efficiency calculated.

(f) *Estimation of chlorine.*

The chlorine produced at the anode was absorbed in sodium hydroxide cooled in ice. The hypochlorite formed was estimated by acidified potassium iodide method.

TABLE I.

*Electrochemical preparation of Sodium hydrosulphite.
Effect of addition of Sodium chloride to the catholyte.*

Current density at the cathode: 2.16 amp./dm.²

Catholyte: 100 ml. aqueous solution containing 30 g. sodium bisulphite and 10 g. sodium chloride.

Anolyte: 10 ml. saturated solution of sodium bicarbonate.

Current passed: 0.8 amp. Temperature: 8°C.

Potential difference: 4 to 5 volts.

Time in hours	Na ₂ S ₂ O ₄ in catholyte. %	Total Na ₂ S ₂ O ₄ formed.* g.	Approximate current efficiency. %
1	2.44	2.44	94.1
2.5	5.68	5.61	86.5
3	6.45	6.35	81.5
4	(crystals) 8.11	7.89	76.0
5	10.35	9.92	76.4
6	11.14	10.60	68.1
7	12.46	11.72	64.5
8	13.63	12.67	61.0
9	12.12	Decomposition	..

* In analysing the catholyte periodically, some solution was removed and with it some hydrosulphite. In arriving at the figures in this column, the hydrosulphite thus removed has been duly taken into account.

Procedure for the electrochemical preparation of hydrosulphite.

Into the electrolytic cell were placed 60 ml. of purified mercury and 100 ml. of an aqueous solution containing 30% sodium bisulphite and 10% sodium chloride. All the air in the cathode chamber had been displaced by purified hydrogen. The temperature of the catholyte was lowered to 8°C. A saturated solution (10 ml.) of sodium bicarbonate was used as anolyte. The stirrer S_1 was set in motion and the current from the D.C. mains was switched on. The current, which was measured by a calibrated ammeter, could be kept constant with the aid of a rheostat. The voltage between the two terminals of the cell was noted by means of an accurate voltmeter. The concentration of hydrosulphite increased with the passage of the current and when the concentration was about 6%, crystals of hydrosulphite were formed. The slurry of the hydrosulphite crystals thus formed was analysed from time to time. The results obtained are given in Table I.

The results (Table I) indicate that the highest concentration of sodium hydrosulphite obtained in the cathode slurry is 13.6% as against 10.7% obtained in the previous work (Patel and Rao, 1949). It is further seen that the current efficiency gradually falls from 94% to 61% during the course of 8 hours, showing that the rate of formation of sodium hydrosulphite gradually drops off and towards the end it has become even negative.

On examination of the catholyte at the end of the experiment, it was found that the solution was slightly alkaline. According to the investigations of Patel and Rao (1949) the optimum pH for the maximum formation of sodium hydrosulphite by the electrochemical reduction of sodium bisulphite is between 5 and

TABLE II.

Effect of sulphur dioxide on hydrosulphite production.

Current density at the mercury cathode: 2.16 amp./dm.²

Catholyte: 100 ml. aqueous solution containing 30 g. sodium bisulphite and 10 g. sodium chloride.

Anolyte: 10 ml. of saturated solution of sodium bicarbonate.

Current passed: 0.8 amp. P.D. = 4 to 5 volts.

pH of the cathode solution: about 5.

Temperature: 8°C.

Time in hours.	SO ₂ passed. g.	Na ₂ S ₂ O ₄ in catholyte. %	Total Na ₂ S ₂ O ₄ formed. g.	Approximate current efficiency. %
1	1.04	2.41	2.41	92.7
2	1.38	4.43	4.39	84.7
3	1.04	6.02	5.91	75.8
4	0.69	(crystals) 7.52	7.30	70.3
5	0.35	9.37	8.97	69.0
6	0.69	11.03	10.48	67.3
7	0.69	13.08	12.27	67.5
8	0.69	15.20	13.98	67.3
9	0.35	15.93	14.58	62.4

5.5. In order to maintain the pH near the optimum value, the alkali produced in the catholyte was carefully neutralised by passing a measured amount of pure sulphur dioxide. Excess of sulphur dioxide passed could be detected by the formation of brown hydrosulphurous acid (dithionous acid, $\text{H}_2\text{S}_2\text{O}_4$) in the catholyte. The results obtained are given in Table II.

The results (Table II) indicate that the concentration of sodium hydrosulphite in the cathode slurry could be increased to 15.9% by maintaining the pH at about 5 by the passage of sulphur dioxide into the catholyte. There was a marked improvement in the current efficiency. The results were found to be reproducible.

In order to reduce the solubility of hydrosulphite still further, the concentration of sodium chloride in the catholyte was raised to 20%. Sulphur dioxide was bubbled into the catholyte as in the previous experiment to control the pH. Results obtained are given in Table III.

TABLE III.

Effect of increased concentration of sodium chloride (20%) on hydrosulphite production.

Current Density at the mercury cathode: 2.16 amp./dm.²

Catholyte: 100 ml. aqueous solution containing 27.4 g. sodium bisulphite and 20 g. sodium chloride.

Anolyte: 10 ml. saturated solution of sodium bicarbonate.

Current passed: 0.8 amp. P.D.: 4 to 5 volts.

Temperature: 8°C.

Time in hours.	SO ₂ passed. g.	Na ₂ S ₂ O ₄ in catholyte. %	Total Na ₂ S ₂ O ₄ formed. g.	Approximate current efficiency. %
	1.38	2.42	2.42	93.2
	1.38	4.49	4.44	85.5
	1.38	(crystals) 6.81	6.66	85.5
	1.04	8.79	8.51	80.0
	0.69	10.99	10.53	81.1
	0.69	12.83	12.18	78.2
	0.35	14.92	14.02	77.1
	0.69	16.99	15.83	76.2
	0.35	18.91	17.44	74.6

The above results indicate that the concentration of sodium hydrosulphite in the cathode slurry is increased to 18.9% by increasing the concentration of sodium chloride to 20%. Increase in concentration of sodium chloride is also found to yield higher current efficiency.

A study of Tables II and III shows that crystallisation of hydrosulphite starts in the catholyte at the hydrosulphite concentrations of 6% and 3% when the corresponding strengths of sodium chloride are 10% and 20% respectively. The sodium chloride in the catholyte has, therefore, a marked effect on hydrosulphite solubility.

The experiments described above clearly indicate that an increased production of sodium hydrosulphite could be obtained when the hydrosulphite is crystallised in the catholyte. To determine the optimum conditions for the production of the hydrosulphite, the following aspects were studied in detail: (1) composition of anolyte, (2) composition of catholyte, (3) effect of temperature, and (4) effect of current density. In all these cases the catholyte was quantitatively analysed for hydrosulphite, bisulphite, thiosulphate, etc. The overall current efficiency was also calculated by the estimation of the total hydrosulphite as described already.

Composition of the anolyte.

In the previous experiments sodium bicarbonate was employed as anolyte. Since the solubility of the bicarbonate is small (about 8%), the cell resistance was high. In order to reduce the cell resistance, sodium bicarbonate solution was replaced by (1) the cathode solution containing sodium bisulphite and sodium chloride, (2) cathode solution containing an excess (suspension) of sodium chloride and (3) aqueous sodium chloride having suspension of solid sodium chloride.

TABLE IV.

Effect of employing aqueous solution of sodium bisulphite and sodium chloride for both anolyte and catholyte.

Current density at the cathode: 2.05 amp./dm.²

Catholyte: 120 ml. aqueous solution containing 28.46% sodium bisulphite and 18.37% sodium chloride.

Anolyte: 10 ml. solution of the same composition as catholyte. Current passed: 0.76 amp.

Cathode: Mercury. Anode: Graphite. Temperature: 5°C. P.D.: 4 to 4.5 volts.

Time in hours.	SO ₂ passed. g./hr.	Composition of filtered catholyte. g. in 100 ml. soln.				Na ₂ S ₂ O ₄ in 100 ml. slurry. g.	Total production in g.		Current efficiency in %	
		Na ₂ S ₂ O ₄	Na ₂ S ₂ O ₃	NaHSO ₃	NaCl		Na ₂ S ₂ O ₄	Cl ₂	Na ₂ S ₂ O ₄	Cl ₂
1	0.35	2.000	..	26.79	17.35	..	2.41	nil	97.6	0.0
2	2.41	2.115	..	26.40	17.09	3.58	4.17	0.27	84.5	13.2
3	1.21	2.060	..	25.95	16.80	5.62	6.30	0.94	85.1	31.2
4	1.38	2.060	..	23.86	16.19	7.47	8.02	1.41	81.3	35.0
5	0.52	2.115	..	23.22	15.53	9.18	9.39	1.74	76.2	34.6
6	1.04	2.115	..	22.57	15.26	11.18	10.86	1.96	73.4	32.4
(Overall values)→							(11.79)		(79.7)	

The results in Table IV show that the current efficiency for hydrosulphite is quite high (79.7%) while that for chlorine is very low (32.4%). No thiosulphate is formed in the catholyte.

It was noticed during the later stages of electrolysis that a brown ring of hydrosulphurous acid (H₂S₂O₄) was formed in the catholyte around the diaphragm. Evidently, the bisulphite in the anolyte was oxidised by chlorine and sulphuric acid was formed. The acid thus formed diffused around the diaphragm producing hydrosulphurous acid at the diaphragm in the catholyte.

In order to reduce the solubility of chlorine in the anolyte, solid sodium chloride was kept in suspension in the anolyte and the effect on the preparation of hydrosulphite and chlorine was studied. The results obtained are given in Table V.

TABLE V.

*Effect of addition of solid sodium chloride to the anolyte.*Current density at the cathode: 2.05 amp./dm.²

Catholyte: 120 ml. aqueous solution containing 28.03% sodium bisulphite and 19.30% sodium chloride.

Anolyte: 10 ml. cathode solution + 6 g. solid sodium chloride. Current passed: 0.76 amp.

Cathode: Mercury. Anode: Graphite. Temperature: 5°C. P.D.: 4 to 4.5 volts.

Time in hours.	SO ₂ passed, g./hr.	Composition of filtered catholyte, g. in 100 ml. soln.				Na ₂ S ₂ O ₄ in 100 ml. slurry, g.	Total production in g.		Current efficiency in %	
		Na ₂ S ₂ O ₄	Na ₂ S ₂ O ₃	NaHSO ₃	NaCl		Na ₂ S ₂ O ₄	Cl ₂	Na ₂ S ₂ O ₄	Cl ₂
1	1.04	2.00	..	25.89	18.52	..	2.41	..	97.6	..
2	1.38	3.339	..	25.37	18.04	3.47	4.09	..	82.9	..
3	1.21	2.449	..	24.44	17.54	5.57	6.42	..	86.8	..
4	1.55	2.393	..	24.04	16.96	7.47	8.32	..	84.3	..
5	1.04	2.393	..	23.87	16.43	9.48	10.16	..	82.3	..
6	0.69	2.449	..	23.18	15.72	12.53	12.83	4.89	86.7	81.1
						(Overall values)→(12.68)			(85.7)	

The results (Table V) indicate that the current efficiency for the production of hydrosulphite and chlorine is 85% and 81% respectively. Thus the addition of solid sodium chloride to the anolyte helped to increase the current efficiency for chlorine.

In subsequent experiments, the anolyte consisted of a saturated solution of sodium chloride containing an excess of the solid. Solid sodium chloride was also added (in suspension) to the catholyte in order to replenish the salt that got consumed during electrolysis. It was found during this experiment that crystals of hydrosulphite were formed during the first hour itself. The results obtained are given in Table VI.

TABLE VI.

*Effect of addition of solid sodium chloride in both the catholyte and the anolyte, the latter having no bisulphite.*Current density at the cathode: 2.05 amp./dm.²

Catholyte: 120 ml. aqueous solution containing 32.42 g. sodium bisulphite. 35 g. solid sodium chloride was added to it. The expanded volume on addition of sodium chloride was 131 ml.

Anolyte: 10 g. sodium chloride + 10 ml. water. Current passed: 0.76 amp.

Cathode: Mercury. Anode: Graphite. Temperature: 5°C. P.D.: 4 to 4.5 volts.)

Time in hours.	SO ₂ passed, g./hr.	Composition of filtered catholyte, g. in 100 ml. soln.				Na ₂ S ₂ O ₄ in 100 ml. slurry, g.	Total production in g.		Current efficiency in %	
		Na ₂ S ₂ O ₄	Na ₂ S ₂ O ₃	NaHSO ₃	NaCl		Na ₂ S ₂ O ₄	Cl ₂	Na ₂ S ₂ O ₄	Cl ₂
1	1.38	1.781	..	21.9	22.9	1.787	2.34	0.89	94.8	88.7
2	2.07	1.781	..	22.7	23.2	3.473	4.46	1.84	90.4	91.6
3	1.73	1.614	..	22.7	23.1	4.920	6.02	2.77	81.3	91.7
4	1.21	1.603	..	20.9	23.2	7.108	8.56	3.74	86.8	92.9
5	1.55	1.447	..	21.7	23.1	9.378	10.87	4.60	88.1	91.4
6	1.04	1.592	..	21.0	22.6	11.540	12.87	5.52	87.0	91.4
						(Overall values)→(13.41)			(90.6)	

The results (Table VI) indicate that the addition of solid sodium chloride to the catholyte lowers the solubility of hydrosulphite from about 2.4% (Table V) to 1.6%. The concentration of bisulphite and chloride in the filtered catholyte remains almost constant throughout the experiment. The current efficiencies for the production of hydrosulphite and chlorine are appreciably enhanced and are nearly of the same order (91%) for both the products. No thiosulphate is noticed in the catholyte.

The results of analysis of sulphur compounds in the filtered catholyte of the above experiment are given in Table VII.

TABLE VII.
Sulphur compounds in the catholyte.

Time in hours.	G-atoms of Sulphur $\times 10^2$				(e) Sulphur in G-Atoms estimated as sulphate $\times 10^2$	(e) - (d)
	(a) $\text{Na}_2\text{S}_2\text{O}_4$	(b) NaHSO_3	(c) $\text{Na}_2\text{S}_2\text{O}_3$	(d) Total (a + b + c)		
1	2.68	27.56	..	30.24	30.93	0.69
2	2.58	27.49	..	30.07	30.29	0.22
3	2.25	26.40	..	28.65	28.93	0.28
5	1.85	23.11	..	24.96	26.31	1.35
6	1.94	21.27	..	23.21	24.57	1.36

It would be noticed from the above table, that the two values for total sulphur agree well, except at the later stages of electrolysis, when diffusion of anolyte into the cathode chamber is likely to be a disturbing influence.

Effect of bisulphite concentration on the production of hydrosulphite.

To study the effect of concentration of the bisulphite, an experiment was conducted in which bisulphite strength was reduced to 8.6%. The results are recorded in Table VIII.

TABLE VIII.
Effect of lower concentration of sodium bisulphite in the catholyte on the production of hydrosulphite.

Current density at the cathode: 2.05 amp./dm.²

Catholyte: 120 ml. aqueous solution containing 11.27 g. sodium bisulphite. 30 g. of solid sodium chloride was added to it. The expanded volume on addition of sodium chloride was 131 ml.

Anolyte: 10 g. sodium chloride + 10 ml. water. Current passed: 0.76 amp.

Cathode: Mercury. Anode: Graphite. Temperature: 5°C. P.D.: 5 volts.

Time in hours.	SO_2 passed, g./hr.	Composition of filtered catholyte, g. in 100 ml. soln.				$\text{Na}_2\text{S}_2\text{O}_4$ in 100 ml. slurry, g.	Total production in g.		Current efficiency in %	
		$\text{Na}_2\text{S}_2\text{O}_4$	$\text{Na}_2\text{S}_2\text{O}_3$	NaHSO_3	NaCl		$\text{Na}_2\text{S}_2\text{O}_4$	Cl_2	$\text{Na}_2\text{S}_2\text{O}_4$	Cl_2
1	1.38	1.837	..	8.45	22.1	..	2.41	0.89	97.6	88.5
2	1.38	3.562	..	7.33	21.6	..	4.60	1.82	93.2	90.5
3	1.73	2.949	..	7.83	20.7	5.17	6.57	2.75	88.8	90.9
4	1.38	2.895	0.358	7.68	20.1	6.68	8.27	3.70	83.8	91.8
5	1.38	3.006	0.469	7.19	19.9	8.80	10.53	4.63	85.4	92.0
6	1.38	2.973	0.591	7.01	18.7	10.42	12.06	5.57	81.5	92.1
(Overall values) \rightarrow (12.52)									(84.6)	

The results of the above table show that the current efficiency for hydrosulphite is lowered from 90.6% (Table VI) to 84.6%. It is to be noted that a small quantity of thiosulphate is produced in the catholyte. This is probably due to the reduction of the hydrosulphite as described later.

The results of analysis of various sulphur compounds of the filtered catholyte drawn out periodically during the above experiment are given in Table IX.

TABLE IX.
Sulphur compounds in the catholyte.

Time in hours.	G-atoms of Sulphur $\times 10^2$				(e) Sulphur in G-Atoms estimated as sulphate $\times 10^2$	(e) (d)
	(a) $\text{Na}_2\text{S}_2\text{O}_4$	(b) NaHSO_3	(c) $\text{Na}_2\text{S}_2\text{O}_3$	(d) Total (a + b + c)		
0	..	10.83	..	10.83	10.96	0.13
1	2.77	10.64	..	13.41	13.58	0.17
2	5.20	8.95	..	14.15	14.35	0.20
3	4.17	8.67	..	12.84	13.11	0.27
4	3.93	8.71	0.53	13.17	13.49	0.32
5	3.90	7.81	0.67	12.38	12.61	0.23
6	3.69	7.28	0.82	11.79	12.13	0.34

It would be noticed from the above results that hydrosulphite, sulphite and thiosulphate seem to be the only three sulphur compounds in solution.

Effect of temperature of electrolysis on the production of hydrosulphite.

In this case, the bisulphite concentration of the catholyte was kept at 25.4% and an excess of solid sodium chloride was maintained in the catholyte. The

TABLE X.

Effect of room temperature on electrochemical preparation of hydrosulphite.

Current density at the cathode: 2.05 amp./dm.²

Catholyte: 120 ml. aqueous solution containing 33.50 g. of sodium bisulphite. 35 g. solid sodium chloride was added to it. The expanded volume on addition of sodium chloride was 132 ml.

Anolyte: 10 g. sodium chloride + 10 ml. water. Current passed: 0.76 amp.

Cathode: Mercury. Anode: Graphite. Temperature: 21°C. \pm 0.5°C. P.D.: 4 to 4.5 volts.

Time in hours.	SO_2 passed. g./hr.	Composition of filtered catholyte, g. in 100 ml. soln.				$\text{Na}_2\text{S}_2\text{O}_4$ in 100 ml. slurry. g.	Total production in g.		Current efficiency in %	
		$\text{Na}_2\text{S}_2\text{O}_4$	$\text{Na}_2\text{S}_2\text{O}_3$	NaHSO_3	NaCl		$\text{Na}_2\text{S}_2\text{O}_4^*$	Cl_2	$\text{Na}_2\text{S}_2\text{O}_4$	Cl_2
1	0.69	1.447	..	23.9	22.7	..	1.91	0.86	77.5	85.3
2	0.94	1.954	0.37	21.7	22.6	2.372	3.07	1.82	62.2	90.6
3	1.21	1.865	0.83	19.8	22.5	3.380	4.22	2.70	57.0	89.3
4	1.38	1.726	1.20	20.4	22.4	4.028	4.82	3.62	48.9	89.0
5	0.72	1.714	1.86	18.7	22.4	5.222	5.86	4.48	47.5	88.9
6	0.60	1.865	2.04	16.3	21.5	6.412	6.62	5.41	44.8	89.6
(Overall values) \rightarrow (9.95)							(67.2)			

*In spite of stirring, uniform slurry of hydrosulphite crystals could not be obtained at room temperature as the crystals were settling down, and hence the appreciable difference in the overall current efficiency and the current efficiency at the end of six hours.

electrolysis was carried out at room temperature. Formation of crystals of hydrosulphite was noticed during the second hour of electrolysis. The results are recorded in Table X.

The results (Table X) show that the overall current efficiency for hydrosulphite dropped down to 67.2% as compared with 90.6% at 5° C. (Table VI). Added to this, considerable quantities of thiosulphate are produced in this case.

Effect of Current Density on the Production of Hydrosulphite.

Experiments were conducted with the current densities of 3.62 and 5.11 amp./dm², and the results are given in Tables XI and XII.

TABLE XI.

Effect of current density on the production of hydrosulphite, current density at the cathode being 3.62 amp./dm.²

Catholyte: 120 ml. aqueous solution containing 35.1 g. NaHSO₃. 35 g. solid sodium chloride was added to it. The expanded volume on addition of sodium chloride was 131 ml.

Anolyte: 10 g. sodium chloride + 10 ml. water. Current passed: 1.34 amp.

Cathode: Mercury. Anode: Graphite. Temperature: 5° C. ± 0.5° C. P.D.: 7 to 7.2 volts.

Time in hours.	SO ₂ passed, g./hr.	Composition of filtered catholyte, g. in 100 ml. soln.				Na ₂ S ₂ O ₄ in 100 ml. slurry, g.	Total production in g.		Current efficiency in %	
		Na ₂ S ₂ O ₄	Na ₂ S ₂ O ₃	NaHSO ₃	NaCl		Na ₂ S ₂ O ₄	Cl ₂	Na ₂ S ₂ O ₄	Cl ₂
1	2.07	2.226	..	23.9	21.2	3.03	4.06	1.39	91.3	78.4
2	1.73	1.837	..	22.5	21.7	6.32	8.04	2.93	92.5	82.6
3	2.07	1.971	..	21.6	21.7	9.45	11.53	4.46	88.4	83.8
4	1.73	1.519	0.495	20.9	21.3	11.97	13.93	5.95	81.0	83.8
5	2.42	1.737	0.547	21.7	20.4	14.58	16.16	7.08	74.3	79.8
6	0.69	1.447	1.525	19.2	19.9	16.80	17.69	8.17	67.8	76.7
(Overall values)→						(19.62)			(75.2)	

TABLE XII.

Effect of current density on the production of hydrosulphite, current density at the cathode being 5.11 amp./dm.²

Catholyte: 120 ml. aqueous solution containing 36.31 g. sodium bisulphite. 35 g. solid sodium chloride was added to it. The expanded volume on addition of sodium chloride was 131 ml.

Anolyte: 10 g. sodium chloride + 10 ml. water. Current Passed: 1.89 amp.

Cathode: Mercury. Anode: Graphite. Temperature: 5° C. ± 1° C. P.D.: 7 to 7.8 volts.

Time in hours.	SO ₂ passed, g./hr.	Composition of filtered catholyte, g. in 100 ml. soln.				Na ₂ S ₂ O ₄ in 100 ml. slurry, g.	Total production in g.		Current efficiency in %	
		Na ₂ S ₂ O ₄	Na ₂ S ₂ O ₃	NaHSO ₃	NaCl		Na ₂ S ₂ O ₄	Cl ₂	Na ₂ S ₂ O ₄	Cl ₂
1	2.07	1.892	..	24.9	21.4	4.25	5.56	2.09	90.6	83.6
2	1.73	1.670	..	23.0	21.2	7.49	9.54	4.26	77.8	85.1
3	3.11	1.697	0.061	22.7	20.4	10.78	13.27	5.98	72.1	79.6
4	2.76	1.692	1.412	22.1	18.0	12.87	14.97	7.80	61.0	78.0
5	1.73	1.781	2.713	19.1	17.9	14.33	15.81	9.54	51.4	76.3
6	1.73	1.614	5.163	18.5	17.0	..	..	10.76	..	71.6
(Overall values)→						(18.94)			(51.5)	

A reference to these tables indicates that the current efficiencies for the production of hydrosulphite is quite high initially, but the value is diminished considerably towards the end of the experiment. The overall current efficiency for hydrosulphite is 75.2% (Table XI) and 51.5% (Table XII) and for chlorine 76.6% and 71.6% respectively. It has to be pointed out that at higher current density, thiosulphate production increased considerably, the final solution (catholyte) having 5.2% of the thiosulphate in solution (Table XII). It can, therefore, be concluded that low current density is advantageous for the production of hydrosulphite.

Maintaining a current density of 2.05 amp./dm.² continuous electrolysis was carried out for a period of 14 hours under the experimental conditions described in Table VI. The overall current efficiency for hydrosulphite was 82.5%, with a total amount of hydrosulphite produced being 28.5 g. Due to large accumulation of solid hydrosulphite in the catholyte, stirring was considerably ineffective and this facilitated the secondary reactions. It is desirable that experiments of long duration could be more successful if the hydrosulphite crystals are removed from the catholyte at frequent intervals. The chlorine evolved at the anode was 12.0 g. with a current efficiency of 84.9%.

DISCUSSION.

As has already been pointed out, attempts by other workers to obtain hydrosulphite by a direct electrochemical method were unsuccessful owing to the decomposition of hydrosulphite in the catholyte. The preparation of hydrosulphite crystals by the direct electrochemical method was successful in this investigation on account of the addition of sodium chloride to the catholyte. In presence of sodium chloride, the hydrosulphite was salted out before its concentration reached a high value, at which the hydrosulphite suffered decomposition at the cathode. Addition of sodium chloride was also found to increase the current efficiency of the electrochemical process due to the maintenance of lower effective concentration of hydrosulphite in the catholyte.

Data presented in Tables II and III indicate that the current efficiency for the production of sodium hydrosulphite was only 62.4%, when 10% sodium chloride was present in the catholyte; whereas the current efficiency rose to 74.6% when the chloride concentration was raised to 20% in the catholyte, other experimental conditions being practically the same. When suspension of the salt was present in both the catholyte and anolyte, the current efficiency rose to 90% (Table VI). This indicates that the concentration of sodium chloride in the catholyte should be as high as possible for the maximum yield of hydrosulphite. In the preparation of pure sodium hydrosulphite crystals, the suspension of sodium chloride should be avoided and the concentration of the sodium chloride should be maintained slightly below that of the saturation value (20%).

The addition of sodium chloride to the catholyte offers certain other advantages. The chloride acts as a cheap source for the sodium amalgam. It also considerably increases the conductivity of the electrolyte. When bisulphite alone was used as the catholyte, the voltage of the cell varied between 6 and 8 volts. On adding sodium chloride to the electrolyte the voltage, however, dropped to 4 to 5 volts, the diaphragm and the current density being the same in the two cases.

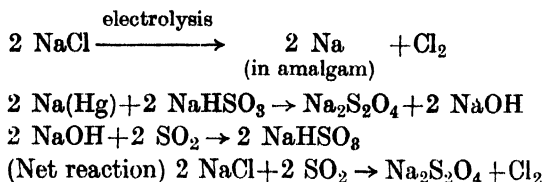
Data presented in Tables I to III indicate that the passage of sulphur dioxide into the catholyte is essential for the continuous production of sodium hydrosulphite. When sulphur dioxide is not introduced, the rate of production of hydrosulphite is slowly reduced and at a certain stage, actually more hydrosulphite is decomposed than can be produced in unit time (Table I). When sulphur dioxide is continuously supplied to the catholyte (Tables II and III), the rate of production of hydrosulphite continues to be high. The sulphur dioxide, apart from providing

the bisulphite, maintains the system at low *pH* to promote the formation of hydrosulphite as shown by Patel and Rao (1949).

It was noticed that when excess of sulphur dioxide was passed in the catholyte, a brownish red coloration developed in the catholyte. The colour acted as an index of the excess of sulphur dioxide in the catholyte. The formation of this red colour is a matter of controversy. Meyer (1903) obtained yellow to orange red coloration when hydrosulphite was acidified. Meyer believed it to be due to the formation of dithionous acid, $\text{H}_2\text{S}_2\text{O}_4$. Basset and Durrant (1927) attributed this coloration to the isomeric compound, sulphylic acid, $(\text{HO})_2\text{S} \cdot \text{SO}_2$, which they suggested as being formed during acidification of hydrosulphite.

For efficient production of hydrosulphite, sodium bisulphite must always be present in adequate strength in the catholyte. It was noticed that if the concentration of bisulphite was low, the yield of hydrosulphite was adversely affected owing to its reduction to thiosulphate. The optimum concentration range of bisulphite in solution was found to be 20 to 30%.

The production of sodium hydrosulphite can be explained on the basis of the following reactions:—



The last reaction accounts for the maintenance of practically a constant strength of sodium bisulphite in the catholyte (Table VI). This process will, therefore, give us a method of preparing sodium hydrosulphite starting from sodium chloride and sulphur dioxide as the raw materials.

The composition of the anolyte is important from the standpoint of yields of both hydrosulphite and chlorine (cf. Tables IV to VI). If bisulphite is present in the anolyte, it gets oxidised to bisulphate. This not only leads to loss of chlorine but makes the anolyte highly acidic. The hydrogen ions in the anolyte would then move towards the cathode resulting in secondary reactions in the catholyte. The adverse effect of the presence of bisulphite in the anolyte can be seen from the fact that the overall current efficiency for hydrosulphite production drops to 79.7% (Table IV); while in absence of bisulphite in the anolyte, the current efficiency is 90.6% (Table VI). It is, therefore, advantageous to employ only sodium chloride in the anolyte.

Data presented in this investigation show that the temperature of the electrolyte has also a profound effect on the yield of hydrosulphite. When the temperature of electrolysis was 21°C., an average current efficiency of 77.5% was obtained during the first hour of electrolysis (Table X). This went down to 67.2% at the end of the sixth hour. When electrolysis was carried out at 5°C., however, the average current efficiency was 90.6% (Table VI). The lower yield of hydrosulphite at elevated temperatures is principally due to the decomposition of the hydrosulphite into bisulphite and thiosulphate.

The optimum current density for production of hydrosulphite seems to be in the region of 2.0 to 3.0 amp./dm.² The loss in current efficiency at higher current densities seems to be partly due to reduction of hydrosulphite to thiosulphate (Patel and Rao, 1949) and partly to the evolution of hydrogen at the cathode.

In conclusion, it can be stated that the present work has indicated definitely that it is possible to obtain solid hydrosulphite by purely electrochemical method without employing any zinc for the reduction of the bisulphite. By carefully controlling the various factors like temperature, current density, composition of electrolyte, etc., it is possible to keep down the formation of thiosulphate.

SUMMARY.*

The electrochemical preparation of sodium hydrosulphite using a mercury cathode has been studied under various experimental conditions. As a result of this investigation, it has been found practicable to prepare solid hydrosulphite by a purely electrochemical method. Sodium chloride and sulphur dioxide are the principal raw materials employed. Chlorine is obtained as a by-product at the anode. Under optimum conditions, the current efficiencies for the production of sodium hydrosulphite and chlorine were found to be 90.6% and 91.4% respectively.

For efficient production of hydrosulphite by the direct electrochemical method, it is desirable:

- (1) to use mercury as a cathode,
- (2) to employ the catholyte containing 20 to 30% sodium bisulphite together with a high concentration of sodium chloride,
- (3) to employ sodium chloride in its saturated aqueous solution as an anolyte,
- (4) to pass sulphur dioxide to help the formation of bisulphite and consequently to maintain low pH in the catholyte,
- (5) to maintain as low a temperature as possible (5°C.) during the electrolysis,
- (6) to employ a current density between 2 and 3 amp./dm.², at the cathode, and
- (7) to periodically remove the crystals of hydrosulphite from the catholyte.

The authors wish to express their grateful thanks to Dr. B. Sanjiva Rao and Sir J. C. Ghosh for their keen interest and instructive criticisms during the progress of the work.

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* The process for the electrochemical manufacture of hydrosulphite, developed as a result of the investigations described in this publication, has been granted an Indian Patent No. 42313, dated 29th November, 1949.

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STUDIES ON THE ELECTROCHEMICAL PREPARATION OF SODIUM HYDROSULPHITE.

PART V. INVESTIGATIONS ON THE PREPARATION OF HYDROSULPHITE USING METALLIC CATHODES OTHER THAN MERCURY

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(Communicated by Dr. J. C. Ghosh, F.N.I.)

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In the previous communication (Part IV), the authors have shown that solid sodium hydrosulphite could be prepared by electrolytic reduction at the mercury cathode, employing sodium chloride and sulphur dioxide as the primary raw materials. Since mercury is an expensive liquid, the suitability of other metallic electrodes is investigated in this paper. K. Jellinek and E. Jellinek (1919) employed platinum, nickel, copper and lead as cathodes and noticed that in the case of lead, hydrosulphite yield was maximum (6.8%), while with other electrodes, the yield was only 3 to 4%. McGlynn and Brown (1929) employed a variety of metallic and amalgamated metallic cathodes and the highest yields (5.5%) were obtained with mercury and amalgamated zinc cathodes. Since the optimum conditions for the preparation of solid hydrosulphite, employing mercury as the cathode, had been fully studied, the suitability of metallic cathodes were also tried under similar conditions.

EXPERIMENTAL.

The electrolytic cell, employed in this investigation, was essentially the same as described in Part IV. The mercury cathode was replaced by a metallic sheet electrode. The materials employed and the methods of analysis were the same as described previously. The experimental conditions employed were as follows: The anolyte was a saturated solution of sodium chloride containing a suspension of the salt. The anode was a graphite rod. The temperature of reduction was 5° C., and the current density at the cathode was 2.05 amp./dm.² The catholyte consisted of 120 ml. of aqueous solution containing about 28% sodium bisulphite and 20% of sodium chloride. Addition of suspension of sodium chloride was avoided in order to find out whether crystals of sodium hydrosulphite were formed during the electrochemical reduction. In this investigation, the cathodes that were employed were (1) zinc, (2) lead, (3) nickel, and (4) iron.

Zinc cathode.—It was noticed during the electrochemical reduction at zinc cathode that no solid got produced in the catholyte for the first one and a half hours, subsequently a greyish white suspension was obtained which on analysis was found to contain zinc hydrosulphite. The cathode was slightly corroded. The details of the results are given in Table I.

It would be noticed from the results of Table I that during the first hour of electrolysis, the current efficiency is greater than 100%. This anomaly is due to the fact that the zinc metal reduces the bisulphite (chemically) to produce hydrosulphite. The current efficiency falls off too rapidly with the progress of time. Added to this, some thiosulphate is also produced during the reduction. The

TABLE I.

Electrochemical preparation of sodium hydrosulphite employing zinc sheet as cathode.

Time in hours.	SO ₂ passed, g./hr	Composition of filtered catholyte, g. in 100 ml. soln.				Na ₂ S ₂ O ₄ in 100 ml. slurry, g.	Total production in g.		Current efficiency in %	
		Na ₂ S ₂ O ₄	Na ₂ S ₂ O ₃	NaHSO ₃	NaCl		Na ₂ S ₂ O ₄	Cl ₂	Na ₂ S ₂ O ₄	Cl ₂
1	0.35	3.118	..	22.4	18.4	..	3.74	0.98	151.7	97.3
2	0.35	3.173	..	22.4	17.3	3.63	4.32	1.61	87.6	79.8
3	1.72	3.312	..	23.3	16.9	4.01	4.71	2.23	63.7	73.9
4	1.72	3.284	0.167	23.2	16.3	4.45	5.09	3.00	51.6	74.5
5	1.38	3.562	0.759	23.5	14.8	5.00	5.49	3.80	44.5	75.4
6	1.38	3.562	1.618	23.9	14.1	5.29	5.79	4.54	39.1	75.2

concentration of bisulphite in the catholyte remains fairly steady while that of sodium chloride goes down from 19.8% to 14.1%.

Lead cathode.—During this experiment, it was noticed that hydrogen was evolved at the cathode surface and no crystallisation of the sodium hydrosulphite took place. The catholyte acquired a slight turbidity due to the presence of lead chloride. The results obtained are given in Table II.

TABLE II.

Electrochemical preparation of sodium hydrosulphite employing lead sheet as cathode.

Time in hours.	SO ₂ passed, g./hr	Composition of filtered catholyte, g. in 100 ml. soln.				Na ₂ S ₂ O ₄ in 100 ml. slurry, g.	Total production in g.		Current efficiency in %	
		Na ₂ S ₂ O ₄	Na ₂ S ₂ O ₃	NaHSO ₃	NaCl		Na ₂ S ₂ O ₄	Cl ₂	Na ₂ S ₂ O ₄	Cl ₂
1	1.04	1.114	..	25.4	18.1	..	1.34	0.80	54.2	79.9
2	1.04	1.837	0.243	24.7	17.4	..	2.15	1.61	43.5	80.1
3	0.69	2.365	0.433	23.7	16.6	2.365	2.72	2.39	36.7	79.1
4	0.35	2.477	0.623	21.0	16.5	2.657	3.02	3.12	30.6	77.5
5	1.04	2.505	1.139	19.5	16.3	2.832	3.18	3.87	25.8	76.8
6	0.35	2.365	2.171	17.3	16.2	2.853	3.18	4.46	21.5	73.8

The results given in Table II indicate that the maximum concentration of hydrosulphite is only 2.85% with a current efficiency of 21.5% at the end of six hours. The thiosulphate production is higher than that at zinc cathode. The bisulphite content diminishes gradually with the progress of electrolysis while concentration of sodium chloride remains more or less constant. The fall in the concentration of bisulphite is due to the reduction in the consumption of sulphur dioxide.

Nickel cathode.—During the electrolysis using nickel cathode, the catholyte acquired a slightly brown colour. No crystals of sodium hydrosulphite were formed. Some hydrogen was evolved at the cathode. There was no detectable corrosion of the cathode. The results obtained are given in Table III.

The results of Table III indicate that there is a rapid decrease in current efficiency for hydrosulphite formation. The current efficiency for chlorine remains at about 77%. There is increasing formation of thiosulphate with the progress of electrolysis.

TABLE III.

Electrochemical preparation of sodium hydrosulphite employing nickel sheet as cathode.

Time in hours	SO ₂ passed g./hr	Composition of filtered catholyte, g. in 100 ml. soln.				Total production in g.		Current efficiency in %	
		Na ₂ S ₂ O ₄	Na ₂ S ₂ O ₃	NaHSO ₃	NaCl	Na ₂ S ₂ O ₄	Cl ₂	Na ₂ S ₂ O ₄	Cl ₂
1	1.04	1.336	..	26.6	18.6	1.60	0.85	65.0	84.7
2	0.35	1.754	0.213	25.3	17.2	2.16	1.54	43.8	76.2
3	1.73	2.115	0.547	25.4	16.9	2.58	2.31	34.8	76.4
4	1.04	2.199	1.139	23.8	16.4	2.67	3.14	27.1	77.8
5	0.35	2.282	1.457	21.6	16.1	2.76	3.91	22.4	77.7
6	0.35	2.255	2.505	17.9	15.8	2.74	4.65	18.5	76.9

Iron cathode.—Evolution of hydrogen was noticed at the iron cathode during the electrolysis. The catholyte developed a white turbidity but the filtrate was colourless. The surface of the cathode was found to have blackened at the end of the experiment. The results obtained in this experiment are given in Table IV.

TABLE IV.

Electrochemical preparation of sodium hydrosulphite employing iron sheet as cathode.

Time in hours.	SO ₂ passed, g./hr	Composition of filtered catholyte, g. in 100 ml. soln.				Na ₂ S ₂ O ₄ in 100 ml. slurry, g.	Total production in g.		Current efficiency in %	
		Na ₂ S ₂ O ₄	Na ₂ S ₂ O ₃	NaHSO ₃	NaCl		Na ₂ S ₂ O ₄	Cl ₂	Na ₂ S ₂ O ₄	Cl ₂
1	1.04	1.336	..	27.1	18.1	..	1.60	0.81	65.0	80.7
2	1.04	1.614	0.35	26.7	17.4	..	1.84	1.66	37.3	82.5
3	0.69	1.670	0.88	25.8	16.6	1.936	2.25	2.40	30.4	79.6
4	0.35	1.726	2.11	22.9	16.5	1.941	2.23	3.20	22.9	79.3
5	1.04	1.848	2.50	22.8	16.3	2.005	2.31	3.90	18.7	77.5
6	0.35	1.892	3.34	22.7	16.2	2.019	2.32	4.47	15.6	74.0

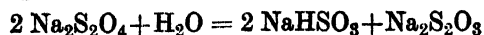
The results represented in Table IV indicate that the current efficiency at the end of the experiment is very low (15.6%) for the production of hydrosulphite. The current efficiency for the production of chlorine varied from 82.5% to 74.0%. Thiosulphate formation was maximum with this cathode.

DISCUSSION.

A scrutiny of the data presented in this paper shows that in presence of metallic cathodes, production of hydrosulphite is low when compared with the experiments with the mercury cathode. The low yield may be attributed to the following: (1) evolution of hydrogen at the cathode, causing dissipation of electrical energy and (2) formation of thiosulphate in the catholyte by reduction of hydrosulphite. The formation of thiosulphate during the preparation of hydrosulphite has been attributed by Elbs and Becker (1904) to the electrolytic reduction of hydrosulphite at the cathode in terms of the reaction:



On the other hand, K. Jellinek (1911) states that the thiosulphite is formed by spontaneous decomposition of hydrosulphite as per equation:



During the course of the preparation of hydrosulphite, employing mercury as the cathode, very little of thiosulphate was produced in the catholyte (Part IV). With the other metal electrodes, however, considerable quantities of thiosulphate were produced. The formation of thiosulphate, therefore, seems to be due to the electrolytic reduction of hydrosulphite rather than to the spontaneous decomposition of the latter.

There is apparently a close correlation between the efficiency of the cathode and its hydrogen over-voltage as shown in Table V.

TABLE V.

Effect of hydrogen over-voltage on the production of hydrosulphite.

Electrode used	Hydrogen over-voltage by		At the end of electrolysis of six hours		
	Newbery (1916).	Caspari (1899).	$\text{Na}_2\text{S}_2\text{O}_4$ in 100 ml. of catholyte. g.	$\text{Na}_2\text{S}_2\text{O}_3$ in 100 ml. of catholyte. g.	Overall current efficiency for $\text{Na}_2\text{S}_2\text{O}_4$. %
Iron	0.18	0.08 (in NaOH soln.)	2.02	3.34	15.64
Nickel	0.18	0.21	2.26	2.51	18.49
Lead	0.46	0.64	2.85	2.17	21.51
Zinc	0.72	0.70	5.29	1.52	39.11
Mercury	0.70	0.78	12.53	Nil	85.70

As the hydrogen over-voltage at the cathode rises, conditions for the formation of hydrosulphite are far more favourable. It is known that hydrogen is discharged much more readily than sodium at cathodes having low hydrogen over-voltage (Mantell, 1940). In the case of the mercury cathode, owing to its high hydrogen over-voltage, conditions are less favourable for the evolution of hydrogen and consequently the liberation of sodium is favoured. The sodium thus produced brings about the reduction of bisulphite to hydrosulphite.

It will be noticed that though zinc and mercury have hydrogen over-voltage of the same order, production of hydrosulphite is much greater at the mercury cathode. This seems to be due to the fact that the sodium liberated at the mercury cathode, readily forms an amalgam. Formation of amalgam leads to conservation of sodium (by reducing its reactivity with water) and makes it more available for the formation of hydrosulphite. A good part of the sodium liberated on the zinc cathode, on the other hand, is lost by its reaction with water. This explains the low current efficiency at the zinc electrode.

SUMMARY.

Electrochemical preparation of sodium hydrosulphite has been carried out using non-mercury cathodes like iron, lead, nickel and zinc, and the results have been compared with those

at a mercury cathode. An explanation is offered for the possible correlation noticed between hydrogen over-voltage of the cathode and its efficiency in the electrochemical reduction of bisulphite to hydrosulphite.

The authors are thankful to Sir J. C. Ghosh and Dr. B. Sanjiva Rao for their keen interest in the work.

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Issued April 21, 1953.

STUDIES ON THE ELECTROCHEMICAL PREPARATION OF SODIUM HYDROSULPHITE.

PART VI. STABILITY AND SOLUBILITY OF SODIUM HYDROSULPHITE IN AQUEOUS SYSTEMS AT VARIOUS TEMPERATURES

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(Communicated by Dr. J. C. Ghosh, F.N.I.)

(Received 7th July; read October 4, 1952.)

The solubility of sodium hydrosulphite in water has been studied by K. Jellinek (1911) but the purity of hydrosulphite was not ascertained by him. Artamonov and Shadrina (1937) have studied the solubility of sodium hydrosulphite in aqueous sodium chloride, sodium hydroxide and alcohol at 20°C., using a sample of hydrosulphite whose purity was only 90%. The effect of temperature on the solubility of hydrosulphite was not determined by these authors.

A need for the systematic investigation on the solubility and stability of pure hydrosulphite in aqueous sodium chloride was keenly felt during the standardisation of optimum conditions for the preparation of sodium hydrosulphite by the electrochemical method (Part IV). The temperature effect on the solubility of hydrosulphite was also very important in this connection. The data were of particular interest since the sample of hydrosulphite was very pure. Since alcohol was employed in washing of sodium hydrosulphite, the effect of aqueous alcohols on the stability and solubility of sodium hydrosulphite was also investigated. In this section, water, aqueous sodium chloride and aqueous alcohol have been employed at various temperatures to determine the solubility and stability of pure hydrosulphite at various temperatures.

EXPERIMENTAL.

Preparation of pure Sodium Hydrosulphite.

Owing to the susceptibility of hydrosulphite to atmospheric oxidation, the preparation of sodium hydrosulphite in a state of purity, presents many difficulties. Furthermore, sodium hydrosulphite in aqueous solution is liable to decompose, even when air is excluded (Meyer, 1903). Hence the filtration and washing of the hydrosulphite had to be carefully controlled and suitable precautions had to be taken in the preparation of hydrosulphite solution prior to the analysis of the salt. After a great deal of experimental work, the following technique was finally adopted.

The hydrosulphite crystals were prepared by the electrochemical method described in Part IV, employing an aqueous solution of 27% bisulphite and 20% sodium chloride in catholyte. The suspension of the hydrosulphite crystals produced in the catholyte was conveyed through the filter tube T_1 to the pyrex sintered glass filter P of 120 ml. capacity (Fig. 1) while an inert atmosphere was maintained in the electrolytic cell. P was closed with a rubber stopper R_3 , through which the hydrosulphite delivery tube T_2 , thermometer A , a graduated separating funnel F_2 , and a three-way stop-cock B_1 passed. P was surrounded by a glass vessel

K which served as a water-bath for the maintenance of constant temperature. At its lower end, P was provided with a three-way stop-cock B_3 to connect it either to

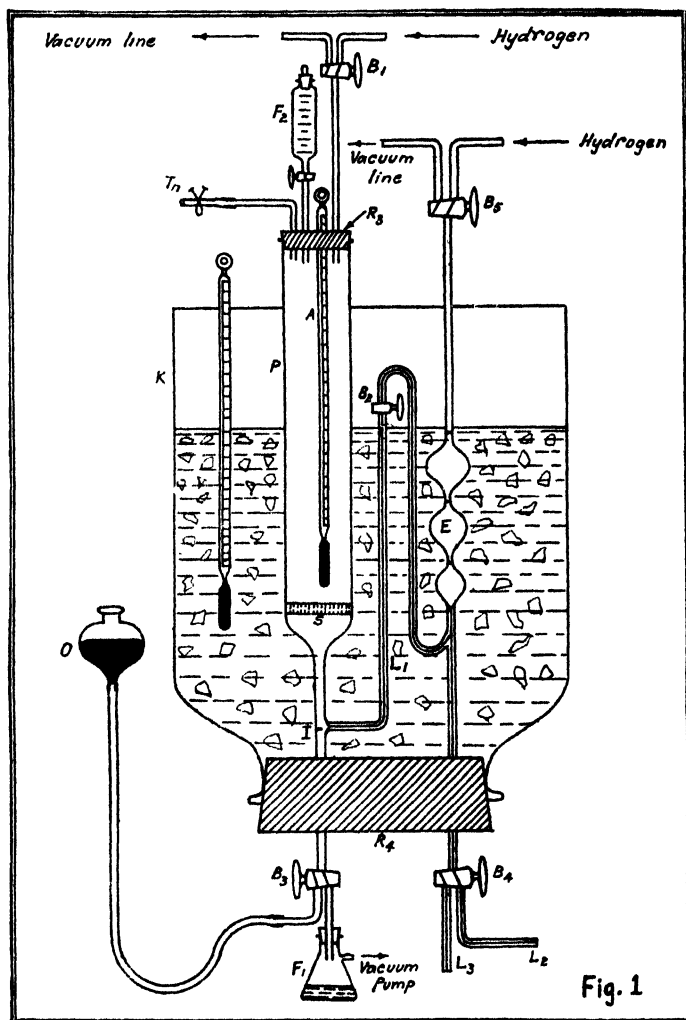


Fig. 1

the filter flask F_1 , or to the mercury reservoir O . The calibrated pipette E could be connected to P by means of the stop-cock B_2 to take out the filtered solution for analysis. The pipette E had three-way glass stop-cocks B_5 and B_4 as in the figure.

PROCEDURE.

The mercury level was first raised to fill the bore of the stop-cock B_3 and all air in the entire apparatus was displaced by hydrogen by suitable manipulation of the stop-cocks B_1 , B_2 , B_3 , B_4 and B_5 . The temperature of the bath K was lowered to about 0°C ., by addition of ice. B_2 was closed and the mercury was brought up to the sintered glass plate S . The cathode slurry was then sucked into the filter P . The filter P was then connected to the hydrogen supply to push back the slurry remaining in the tube T_n . The pinch-cock at T_n was closed. The

mercury in the filter *P* was then lowered to the level *I*, *B*₂ was opened and some mother liquor was sucked into the pipette *E*. *B*₂ was then closed, *E* was connected to the hydrogen supply and the liquid was allowed to drain off through *L*₃. The pipette *E* was refilled with the mother liquor and aliquots were taken through *L*, for analysis. The sample was analysed for hydrosulphite, bisulphite, thiosulphate, chloride and total sulphur as described in Part IV.

After removal for analysis, the entire mother liquor was drained off into the flask *F*₁. All the wash liquids and water that were added to the hydrosulphite crystals were free from dissolved air and pre-cooled to 0° C. The wash liquids in the funnel *F*₂ were added in small quantities at a time into the filter *P*. The contents of *P* were then intimately mixed by pulsations in the liquid caused by moving the mercury reservoir up and down and the wash liquid analysed to know the extent of removal of impurities and the superfluous wash liquid was drained off into flask *F*₁. It can be stated that the hydrosulphite does not get decomposed in presence of mercury (Rabinowitsch and Fokin, 1930). The crystals were washed with a small quantity of air-free distilled water (0° C.), followed by three washes with 60% alcohol to remove the contamination of sodium chloride and sodium bisulphite. The crystals were then washed with 5 ml. of aqueous sodium hydroxide (0.5%) to avoid any acidity. It was then followed by two washes with distilled water and finally dissolved in 20 ml. of distilled water and the solution was well stirred by inducing pulsations in the mercury. In order to determine the purity of hydrosulphite, aliquots were analysed for hydrosulphite, bisulphite, thiosulphate, chloride and 'total sulphur'. The following table gives the purity of a representative sample.

TABLE I.

Purity of Hydrosulphite crystals.

1. Na ₂ S ₂ O ₄ in 100 ml. solution	=	11.64 g.
2. NaHSO ₃ " "	=	0.032 g.
3. Na ₂ S ₂ O ₃ " "	=	nil.
4. NaCl " "	=	0.010 g.
5. BaSO ₄ gravimetrically corresponding to total sulphur in 1 ml. solution	=	0.3136 g.
6. BaSO ₄ corresponding to hydrosulphite + bisulphite in 1 ml. solution	=	0.3129 g.

The above results indicate that the sample of hydrosulphite prepared was at least 99.6% pure.

Solubility of hydrated Sodium Hydrosulphite in water.

For the determination of the solubility of sodium hydrosulphite in water at low temperatures, the pure crystals of hydrosulphite prepared in the filter *P* were cooled to -2.8° C. by means of ice and salt, and air-free distilled water at 0° C. was added to the crystals. The mixture was stirred by pulsations of mercury for about fifteen minutes for the attainment of the equilibrium. The mercury in the filter was then moved up and down to rinse the lower parts of the vessel thoroughly. The solution in equilibrium with the solid was then transferred to the graduated pipette *E* under the hydrogen atmosphere as described already. Aliquots of the solution were employed for the analysis of hydrosulphite, thiosulphate, sulphite and 'total sulphur'. It was found that the solution was free from sulphur compounds other than hydrosulphite. Duplicate analytical values were obtained to confirm the attainment of the equilibrium between the solid hydrosulphite and the solution. After determining the solubility at -2.8° C., the temperature of the bath was raised to 0° C., and the solubility determined at this temperature. The

same procedure was adopted to determine the solubility of hydrosulphite at 10° C. and 20° C., employing fresh samples of hydrosulphite. It has to be stated, however, that at 20° C., the stability of hydrosulphite was poor and the measurements had to be made very rapidly. The results are given in Table II.

TABLE II.

Solubility of hydrated Sodium Hydrosulphite in water.
Purity of hydrosulphite crystals = 99.9%.

Temperature ° C.	Weight in g. of solid in 100 ml. Solution.		
	Na ₂ S ₂ O ₄	NaHSO ₃	Na ₂ S ₂ O ₃
-2.8	11.06	..	..
0.0	11.86	..	..
10.0	15.55	..	..
20.0	18.16	..	..

The results (Table II) indicate that the solubility of hydrosulphite in water increases gradually with a rise in temperature.

Solubility of hydrated Sodium Hydrosulphite in aqueous sodium chloride.

For the determination of the solubility of hydrosulphite in sodium chloride solutions, the purified crystals of hydrosulphite were rinsed twice with about 8 ml. of 10% aqueous sodium chloride (A.R.) solution (at 0° C.). The wash liquid was removed into the flask *F*₁. The solid in the filter was then mixed with about 12 ml. of 10% sodium chloride solution and the contents were well stirred for the attainment of the equilibrium. The rest of the procedure was the same as described for the determination of solubility in water. Similarly, solubility determinations were carried out employing fresh samples of hydrosulphite in 20% aqueous sodium chloride solution. The results obtained for solubility of hydrosulphite in 10% and 20% sodium chloride solutions are given in Table III.

TABLE III.

Solubility of hydrated Sodium Hydrosulphite in 10% and 20% sodium chloride solutions at various temperatures.

Concentration of NaCl soln.	Temperature °C.	Weight in g. of solid in 100 ml. soln.			Remarks.
		Na ₂ S ₂ O ₄	NaHSO ₃	Na ₂ S ₂ O ₃	
10%	-2.2	5.90	} Slight decomposition. Decomposition of hydrosulphite.
"	1.0	7.04	..	..
"	10.8	8.74	0.85	0.11	
"	20.4	10.44	1.76	0.65	
"	30.0	10.27	4.13	2.69	
20%	-2.0	2.50	} Slight decomposition. Decomposition of hydrosulphite.
"	0.2	2.72	..	..
"	10.6	3.61	0.51	0.23	
"	20.2	4.64	n.d.	n.d.	
"	30.5	5.73	1.51	0.78	
"	40.8	6.44	2.84	1.82	
"	50.7	4.53	8.57	7.23	

The results of Table III indicate that there is a considerable diminution in solubility of hydrosulphite with the increase in concentration of sodium chloride. The stability of hydrosulphite, however, diminishes considerably with an increase in temperature.

Solubility of hydrated Sodium Hydrosulphite in aqueous ethanol at various temperatures.

The procedure adopted for the determination of the solubility of sodium hydrosulphite employing aqueous alcohol as the solvent was very similar to that used in the case of aqueous sodium chloride. The results are given in Table IV.

TABLE IV.

Solubility of hydrated Sodium Hydrosulphite in different concentrations of aqueous alcohol at various temperatures.

Concentration of alcohol % (by vol.)	Temperature °C.	Weight in g. of solid in 100 ml. soln.			Remarks.
		$\text{Na}_2\text{S}_2\text{O}_4$	NaHSO_3	$\text{Na}_2\text{S}_2\text{O}_3$	
20	0.5	4.71	} Decomposition of hydrosulphite.
"	11.0	6.07	..	..
"	21.0	7.83	..	..
"	31.2	9.87	0.35	..	
"	40.5	11.66	1.18	0.12	
"	51.0	10.27	5.38	3.27	
40	11.0	1.82	} Decomposition of hydrosulphite.
"	20.0	2.56	..	..
"	30.4	3.41	..	..
"	41.0	3.74	1.56	0.14	
"	50.6	4.60	3.22	2.19	
50	0.2	0.89	} Decomposition of hydrosulphite.
"	10.2	1.00	..	..
"	20.1	1.16	..	..
"	30.2	1.31	..	..
"	40.6	1.96	1.47	0.15	
"	50.4	2.64	2.27	1.15	
"	60.0	2.96	4.18	2.08	
"	64 ± 0.5	2.42	5.92	2.87	
"	68 ± 1	1.63	7.11	5.07	
60	31.0	1.03	} Decomposition of hydrosulphite.
"	40.0	1.22	0.10	..	
"	55.0	1.36	1.52	1.01	
"	60.0	1.49	2.37	1.57	
"	70 ± 1	1.23	2.62	1.80	
"	75 ± 1	0.95	3.58	2.52	
70	1.2	0.10	} Decomposition of hydrosulphite.
"	20.6	0.12	..	..
"	40.6	0.24	..	..
"	51 ± 0.5	0.38	0.95	0.43	
"	55.0	0.45	1.40	0.78	
"	60.0	0.58	1.52	0.88	
"	63.4	0.62	1.98	1.20	
"	70 ± 1	0.46	1.80	1.01	
"	74 ± 1	0.36	1.66	1.18	

It will be observed from the results (Table IV) that the solubility of hydrosulphite diminishes with the increase in concentration of alcohol. The stability of hydrosulphite, however, is increased considerably in presence of alcohol. The effect of temperature on the solubility of hydrosulphite becomes less marked as the concentration of alcohol increases. The solubility data are not very accurate beyond 30°C ., because of the presence of large quantities of products of decomposition of hydrosulphite. The solubility values are decreased beyond 60°C ., due to the dehydration of the hydrosulphite at its transition temperature. At this temperature, it was noticed that the crystals would become powdery and dense.

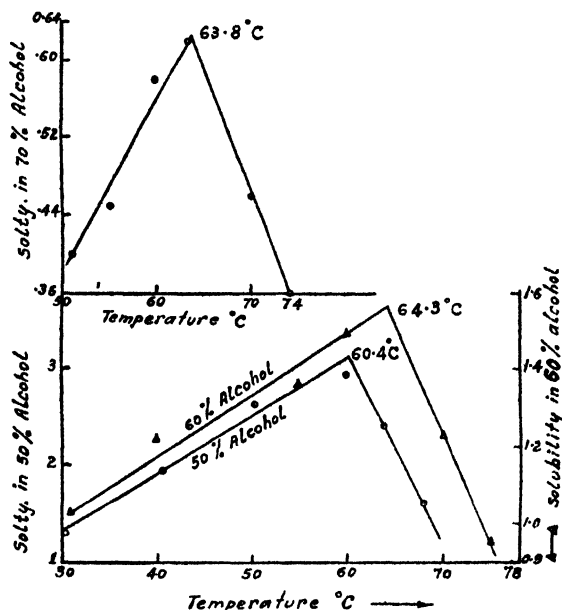


FIG. 2. Transition point of sodium hydrosulphite in presence of different concentrations of alcohol.

The transition point of the hydrosulphite as read from Fig. 2 is 60.4°C ., 64.3°C ., and 63.8°C ., in 50%, 60% and 70% alcohol respectively. The solubility in 85% alcohol was also determined but it was found to be very low (0.062%). The effect of temperature was also noticed to be comparatively small. The transition point was noticed to be about 60.5°C .

DISCUSSION.

Solubility of Hydrosulphite in aqueous media.

The determination of solubility of hydrosulphite in water has been studied only by K. Jellinek who carried out two sets of determinations: one published in 1911 (Jellinek, 1911) and the second a year later (Jellinek, 1912). In the following table, the values obtained by K. Jellinek are compared with those obtained by the present authors.

The present values are in general, intermediate between the values obtained by Jellinek in 1911 and in 1912. In determining the solubilities, Jellinek (1911) obtained the hydrosulphite at 20°C ., by salting it out with sodium chloride. At 20°C ., it has been shown in the present work that the hydrosulphite suffers appreciable decomposition and it is, therefore, likely that this factor has to a certain extent

TABLE V.

Comparison of solubility of Sodium Hydrosulphite in water at various temperatures.

Temperature °C.	Solubility of hydrosulphite by K. Jellinek in %		Solubility of hydrosulphite determined in %
	1911	1912	
1.0	14.9	12.85	12.25
10.0	16.7	14.40	15.55
20.0	19.1	16.46	18.16

affected the values obtained by Jellinek. The purity of hydrosulphite crystals used in the present work was at least 99.6%. Furthermore, in each solubility determination, the saturated solution was analysed for impurities like bisulphite and thiosulphate, produced by hydrosulphite decomposition. It can, therefore, be claimed that the solubility data presented in this paper are of greater accuracy.

As is to be expected, the solubility of sodium hydrosulphite is much less in salt solutions than in water, owing to the common ion effect (compare Tables II and III).

The solubility of the hydrosulphite (Table II) is also diminished by an increase in the concentration of alcohol (Table IV).

Using sodium hydrosulphite of 90% purity, Artamonov and Shadrina (1937) have found that the solubility of hydrosulphite at 20°C., in aqueous solutions containing 20% sodium chloride and 20% alcohol are 10.2% and 9.9% respectively. The corresponding values obtained in the present work are much lower, 4.6% (Table III) and 7.7% (Table IV). As the details of the procedure employed by the above workers are not known, it is difficult to account for the divergence in values. It can, however, be stated that the hydrosulphite employed in the present investigation is far purer (99.6%) than that employed (90%) by the previous workers.

The results of Tables II and III show that with a rise in temperature, the solubility in water and aqueous sodium chloride increases. In aqueous alcohol of lower than 50% strength (Table IV), the effect of temperature is pronounced, but the temperature effect is diminished as the strength of alcohol increases.

Stability of Hydrosulphite in aqueous media.

As already pointed out the solubility of hydrosulphite in water could not be measured with great accuracy at temperatures above 20°C., owing to the rapid decomposition of the salt. Thus when the temperature of the aqueous hydrosulphite was raised to 30°C., the solution darkened rapidly and on standing for about 15 minutes, was found to have a good deal of bisulphite and thiosulphate, the strength of hydrosulphite dropping to 11.15 g., while the saturated solution at 20°C., had 18.16 g. of hydrosulphite in 100 ml. solution. Even at 20°C., the hydrosulphite solution was markedly unstable and yielded 2.5% bisulphite in 25 minutes, the hydrosulphite concentration dropping to 16.34% from its original value of 18.16%. Thus, concentrated solutions are more susceptible to decomposition, and the rate of decomposition increases with rise in temperature. Seyewetz and Kalmar (1932) also came to the same conclusion. Saturated solutions of hydrosulphite can, however, be preserved only at very low temperatures (at 0°C. or below). Thus a saturated solution of hydrosulphite in contact with solid dihydrate, in an inert atmosphere, when preserved for about 20 hours at 0°C., during the present work, suffered a decomposition by about 1% only. On account of the greater stability of hydrosulphite at low temperatures, MacIntyre (1920) patented

a process for preservation of hydrosulphite liquors at about 0° C., in the absence of oxidising gases.

It is evident from Table IV that the stability of hydrosulphite solution is enhanced by the presence of alcohol in the solution. Hydrosulphite in 20% alcohol is found to be stable only up to 21° C., while in 70% alcohol the hydrosulphite is comparatively stable even at higher temperature (up to 50° C.).

Transition point of Hydrosulphite in Alcohol.

The transition temperatures as determined from Fig. 2 are 60.4° C., 64.3° C., and 63.8° C., while the corresponding alcoholic concentrations are 50%, 60% and 70%. The value for 50% alcohol seems to be vitiated by the high rate of decomposition of hydrosulphite.

CONCLUSION.

It can be stated that the stability of hydrosulphite is relatively high at low temperatures. For the electrochemical preparation of hydrosulphite, therefore, low temperatures have to be employed. The addition of sodium chloride to the catholyte, is also highly beneficial as it considerably reduces the solubility of hydrosulphite and thus increases the stability of the salt.

The presence of alcohol increases the stability of hydrosulphite. Alcohol (60%) is, therefore, a very good reagent for washing out the impurities from hydrosulphite. Absolute alcohol cannot, however, be employed for washing since the impurities present in hydrosulphite are almost insoluble. 60% alcohol as a wash liquid has definite advantages over the reagents (aqueous sodium chloride and water) employed by Jellinek (1911), and Christiansen and Norton (1922).

SUMMARY.

(1) A new design has been given for the construction of an apparatus to determine the solubility of unstable substances in an inert atmosphere.

(2) Using this apparatus, the solubility of sodium hydrosulphite crystals has been determined (a) in water over the range -2.8° C. to 20° C., (b) in 10% and 20% aqueous sodium chloride over the range 0° C. to 20° C., and (c) in aqueous alcohol of different strengths from 0° C. to 70° C.

(3) Solubility studies with 60%, 70% and 85% aqueous alcohols indicate that the transition temperatures of the dihydrate to anhydrous sodium hydrosulphite are 64.3° C., 63.8° C., and 60.5° C., respectively.

The authors are thankful to Dr. B. Sanjiva Rao for his keen interest in the work.

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STUDIES ON THE ELECTROCHEMICAL PREPARATION OF SODIUM HYDROSULPHITE.

PART VII. STUDIES ON TRANSITION POINT OF SODIUM HYDROSULPHITE CRYSTALS

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(Communicated by Dr. J. C. Ghosh, F.N.I.)

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It is well known that anhydrous hydrosulphite keeps well, while the hydrated salt is quite unstable. The usual commercial practice, therefore, is to render the hydrosulphite anhydrous. According to the patent literature on hydrosulphite, the dehydration of the salt is carried out at about 60°C. by heating the crystals alone (Badische Anilin- und Soda-Fabrik, 1906) or with reagents like alcohol (Höchst, 1906) or sodium chloride (Badische Anilin- und Soda-Fabrik, 1905) or by heating in vacuum the solution of hydrosulphite in presence of a salting out agent above its transition point (Nitzschke, 1941). K. Jellinek (1911) heats the crystals over the range 50°C. to 70°C., either with alcohol or with a saturated solution of sodium chloride. Pratt (1924) carries out the dehydration in presence of sodium chloride at about 60°C. In connection with the dehydration of hydrosulphite, accurate information about the transition from the dihydrate to the anhydrous form, is of considerable value. In chemical literature, however, information about this transition is very meagre, the only reference to any determination of the transition point being the work of Bazlen (1905) who found that transition took place at about 52°C., in presence of alcohol. In the present investigation, a systematic study was made of the transition point of sodium hydrosulphite dihydrate since it was available in pure form.

EXPERIMENTAL.

Preliminary experiments were carried out to determine, in the case of hydrosulphite, the suitability of the usual methods of determining transition temperature. It was found, however, that some of these methods were not at all suitable. The dilatometric method, for example, was tried employing toluene, kerosene or alcohol as the liquid medium surrounding the crystals. This, however, did not succeed, as practical difficulties were encountered owing to the evolution of sulphur dioxide in the dilatometer, due to the decomposition of the hydrosulphite. In fact, when the salt ($\text{Na}_2\text{S}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$) is heated in an inert atmosphere, the solid is decomposed at about 80°C. with an evolution of heat. The solubility method and the electrical conductivity method of determining the transition temperature were not practicable due to continuous decomposition of hydrosulphite at elevated temperatures. Owing to this decomposition, the dehydration in industrial practice is carried out by heating the crystals of hydrosulphite in presence of sodium chloride (Riegel, 1942). Information about the transition temperature of hydrosulphite in presence of sodium chloride is, therefore, of particular importance. The methods mentioned above could not be employed for the determination of transition temperature in presence of sodium chloride. The thermometric method, however, was found to be fairly satisfactory.

Transition Point of Sodium Hydrosulphite crystals in presence of Sodium Chloride.

For the determination of the transition temperature, the apparatus used was the same (Fig. 1, Part VI) as previously described. The modification introduced was that the vessel *P* was surrounded by an air-jacket. The water bath was well insulated and heated electrically so as to ensure uniform rise in temperature. The water in the bath was stirred well. The crystals of sodium hydrosulphite were prepared by electrochemical method and purified at 0°C ., as described in Part VI. The crystals were then washed twice at 0°C ., with about 10 ml. of a saturated aqueous solution of sodium chloride. The analysis of the wash liquor showed that the hydrosulphite was free from thiosulphate, bisulphite and other sulphur compounds.

For the determination of the transition temperature, the mercury in the apparatus was brought to the sintered glass plate *S* and 8 ml. of the saturated solution of sodium chloride was added to the crystals. In order to confirm the attainment of equilibrium, the hydrated crystals were mixed with anhydrous hydrosulphite. The crystals were gently stirred by the thermometer and the supply of nitrogen maintained in the vessel *P*. The water bath was heated gradually. The temperatures were noted at one minute intervals. The results obtained are given in Fig. 1.

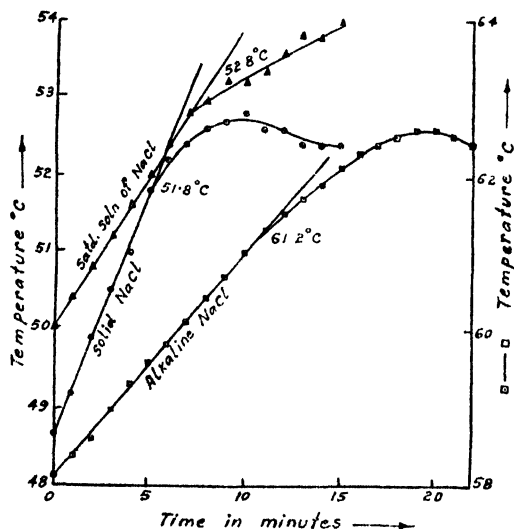


FIG. 1. Transition temperature of sodium hydrosulphite in presence of sodium chloride.

It is seen that the break in the curve, Fig. 1, occurs at 52.8°C . This temperature is, therefore, taken to be the transition point of sodium hydrosulphite in presence of solution of sodium chloride, which is practically saturated.

The temperature of the bath was raised by 0.4°C ., per minute. Slower rate of heating was not desirable on account of the decomposition of the hydrosulphite. During the transition, the crystals of the dihydrate changed over to a sand-like granular powder, which settled down on the filter plate in the vessel *P*. In order to determine roughly the extent of decomposition of hydrosulphite during transition, the liquid phase was analysed for hydrosulphite, bisulphite and thiosulphate at the end of the experiment. The solid was washed and dried as described later and the composition determined. The results obtained are given in Table I.

Employing the same technique, the transition temperatures of sodium hydrosulphite were determined in presence of (a) a suspension of solid sodium chloride in its saturated aqueous solution, and (b) an aqueous solution of sodium chloride containing 5% sodium hydroxide. The latter system was tried, in view of general impression that alkali stabilises hydrosulphite. The corresponding curves are given in Fig. 1; the transition points as read from these graphs and the data pertaining to decomposition of hydrosulphite are presented in Table I.

TABLE I.

Transition Temperature of Sodium Hydrosulphite Crystals in presence of Sodium Chloride.

Expt. No.	Reagent used. 8 ml. in each case.	Transition temperature obtained. °C.	Approx. weight of anhydrous hydrosulphite obtained. g.	Salts present in liquid phase at the end of the dehydration process in 100 ml. solution, g.		
				$\text{Na}_2\text{S}_2\text{O}_4$	NaHSO_3	$\text{Na}_2\text{S}_2\text{O}_3$
1	Saturated NaCl soln.	52.8	12	5.9	1.3	..
2	Saturated NaCl soln. + 1.5 g. of solid NaCl.	51.8	14	2.8	1.1	..
3	Alkaline NaCl soln.	61.2	13	4.8	4.0	0.7

It is clear from the data represented above that the dehydration of crystals of hydrosulphite is best effected in presence of a saturated solution of sodium chloride containing purified common salt. While in presence of a saturated solution of sodium chloride, the transition takes place at 52.8° C., the point is further lowered to 51.8° C., by the presence of solid salt; the alkali, on the other hand, raises the temperature to 61.2° C.

Transition Point of Sodium Hydrosulphite in presence of various Sodium salts.

The dehydration of sodium hydrosulphite crystals was also studied in presence of various foreign substances such as sodium sulphate, sodium nitrate, tri-sodium

TABLE II.

Expt. No.	Reagent surrounding the crystals. 8 ml. in each case.	Transition temperature obtained. °C.	Salts present in liquid phase at the end of the dehydration process in 100 ml. solution, g.		
			$\text{Na}_2\text{S}_2\text{O}_4$	NaHSO_3	$\text{Na}_2\text{S}_2\text{O}_3$
1	Saturated solution of Na_2SO_4 at 40° C.	67.7	9.2	1.8	..
2	100 g. NaNO_3 dissolved in 100 ml. water.	57.3	4.4	3.1	..
3	Saturated solution of Na_3PO_4 at 50° C.	62.1	12.6	0.1	..
4	Saturated soln. of Na_2HPO_4 at 50° C.	61.7	7.5 (lower layer) 0.2 (upper layer)	9.8 0.6	4.4 ..

phosphate and di-sodium hydrogen phosphate, employing about 15 g. of the crystals. The transition temperatures obtained with various media are given in Table II. Data relating to decomposition products of hydrosulphite in liquid phase are also given in Table II. It was noted that two layers were formed in the liquid phase during the dehydration of hydrosulphite in presence of disodium hydrogen phosphate.

The results given in Table II indicate that the transition temperature varies with the nature of the foreign substance surrounding the crystals. Hydrosulphite decomposition was minimum in presence of tri-sodium phosphate.

Transition Point of Sodium Hydrosulphite in presence of different concentrations of alcohol.

Employing the procedure already described, a study was made of the transition temperature of sodium hydrosulphite in presence of the following concentrations of alcohol (by volume): (a) 70%, (b) 85%, and (c) 99.8%. The transition temperatures are given in Table III, as read from data plotted in Fig. 2. Data relating

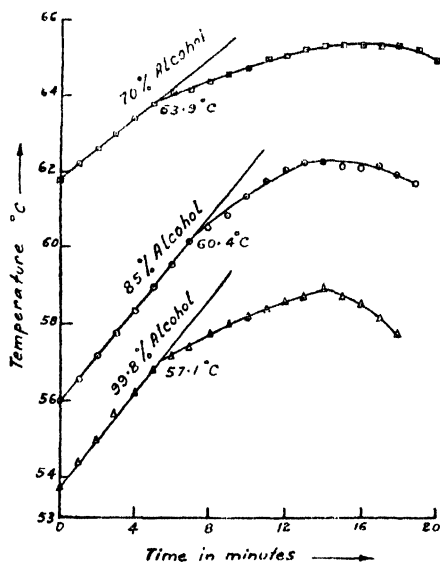


FIG. 2. Transition point of hydrosulphite in presence of various concentrations of alcohol.

TABLE III.

Transition Temperature of Sodium Hydrosulphite in presence of various concentrations of alcohol.

Expt. No.	Concentration of alcohol % (by volume).	Transition temperature obtained. °C.	Salts present in the liquid phase at the end of dehydration process in 100 ml. solution, g.		
			$\text{Na}_2\text{S}_2\text{O}_4$	NaHSO_3	$\text{Na}_2\text{S}_2\text{O}_3$
1	70.0	63.9	2.78	3.08	0.78
2	85.0	60.4	0.92	2.02	0.34
3	99.8	57.1	0.14	1.50	..

to decomposition products of hydrosulphite in liquid phase are also given in the same table. Unlike the granular type of anhydrous hydrosulphite obtained in the case of dehydration in presence of sodium chloride, the product obtained with alcohol was a fine powder, which was found to have comparatively poor keeping quality.

The results of the above table indicate that hydrosulphite decomposition is least in presence of absolute alcohol.

The transition temperature of the hydrosulphite in presence of 60% alcohol was only 60° C. This abnormally low value was due to the appreciable decomposition of hydrosulphite at the elevated temperature.

The transition temperature of sodium hydrosulphite, in absence of stabilising foreign substances, cannot be determined experimentally, owing to the marked decomposition that takes place, during transition. An approximate idea of the transition temperature can, however, be obtained by extrapolation to zero alcohol concentration of the data presented in Table III. The value was found to be 79.4° C.

Stability of anhydrous Hydrosulphite on storage.

To obtain anhydrous hydrosulphite, the crystals were heated with various reagents till the dehydration was complete. The mother liquor was drained off and the anhydrous salt was washed twice with hot 95% alcohol and dried in vacuum at 92° C. The sample was stored in glass stoppered bottles and kept over calcium chloride in a desiccator and analysed after one month. The percentage decomposition of hydrosulphite on storage is given in Table IV.

TABLE IV.
Comparison of the stability of Hydrosulphite on storage.

Method of dehydration.	Purity of hydrosulphite.		Decomposition %
	When prepared.	After one month's storage.	
Saturated solution of NaCl containing solid NaCl.	96.8	94.04 93.90 (after 10 months).	2.9 3.0
Saturated solution of Na ₃ PO ₄ at 50° C.	95.0	92.85	2.3
Solution of NaCl + 5% NaOH ..	92.4	90.96	1.6
Absolute alcohol	92.4	86.12 (after 15 days).	6.8

It is seen from the above table that hydrosulphite dehydrated in presence of sodium salts is more stable than that dehydrated in presence of alcohol.

DISCUSSION.

Transition Temperature of Sodium Hydrosulphite.

When sodium hydrosulphite is heated near the transition temperature, there is absorption of heat due to the dehydration of the salt. At the same time, there is the evolution of heat due to the decomposition of the hydrosulphite (10,350 cal./mol., Deines and Elstner, 1930). The temperature recorded experimentally will be the resultant of these two opposing factors. Hence the transition point curves are not typical.

That the transition temperature of sodium hydrosulphite is influenced by the nature of the surrounding media, is well established by the data presented in Tables I, II and III. This important fact was overlooked by Jellinek (1911) who states that the transition temperature of hydrosulphite should change very little with a change in the medium. In fact, the transition point, as a general rule, is dependent on the activity of water in the surrounding media. If the surrounding medium contains other salts, the transition temperature will naturally be lowered. In the present investigation, the transition point of sodium hydrosulphite was found to range from 51.8°C. , in presence of sodium chloride (Table I) to 67.7°C. , in a saturated solution of sodium sulphate (Table II). These results also indicate that the transition point of sodium hydrosulphite is not 52°C. , as claimed by Bazlen (1905) and accepted by subsequent authors (Pratt, 1924; Seidell, 1940). The extrapolated value for the transition temperature of the hydrosulphite, in absence of foreign substances, is 79.4°C.

The transition temperatures of the salt determined by the solubility method (Part VI) are compared with those obtained by the thermometric method in Table V. It is clear from this table that there is close agreement between the values obtained by the two methods.

TABLE V.

Comparative values of Transition Point of Sodium Hydrosulphite as obtained by the thermometric and solubility methods.

Strength of alcohol. %	Transition temperature in $^{\circ}\text{C.}$	
	By solubility method.	By thermometric method.
60	64.3	..
70	63.8	63.9
85	60.5	60.4
99.8	..	57.1

Influence of the media on the nature of the anhydrous Sodium Hydrosulphite.

It has already been pointed out that when hydrosulphite was dehydrated by heating in presence of alcohol, the anhydrous substance obtained was in the form of very fine powder; while that dehydrated in presence of sodium chloride was in the form of granules. The maximum purity of the alcohol treated hydrosulphite was only 92.4%; while salt of 96.8% purity was obtained by treatment in presence of sodium chloride. Jellinek (1911) could obtain hydrosulphite of only 82% purity by treatment with alcohol. The physical condition of hydrosulphite is of considerable practical importance as this determines the keeping quality of the product (Table IV). Finely divided hydrosulphite is more liable to decomposition than the coarse powder. Christiansen and Norton (1922) also observed rapid decomposition with finely ground hydrosulphite.

The best process of dehydration of hydrosulphite was to heat the crystals at 52°C. , in presence of solid sodium chloride enough to form saturated solution with the water of dehydration of the crystals. The anhydrous hydrosulphite obtained in this way was found to have good keeping quality.

SUMMARY.

Dehydration of sodium hydrosulphite has been carried out in presence of aqueous ethanol, sodium chloride, sodium nitrate, sodium sulphate, tri-sodium phosphate and di-sodium hydrogen phosphate. The transition temperature varies considerably (52°C. to 67.7°C.) with the nature of

the medium employed for dehydration. The transition temperature in the absence of foreign substances has been found to be 79.4° C., by extrapolation. Direct determination of this temperature is not practicable owing to the decomposition that sets in during transition. Dehydration of hydrosulphite is best effected by heating the crystals at 52° C., in presence of a saturated solution of sodium chloride.

The author wishes to acknowledge his indebtedness to Dr. M. R. A. Rao and Dr. B. Sanjiva Rao for their keen interest and instructive suggestions during the progress of the work.

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ON THE STRUCTURE OF THE PITUITARY AND THYROID OF *CHANOS CHANOS* (FORSKÅL)

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Mandapam Camp.*¹

(Communicated by Dr. N. K. Panikkar, F.N.I.)

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INTRODUCTION.

The fry and fingerlings of the milk-fish *Chanos chanos* are known to occur in abundance in the shallow tidal creeks at several places along the coast of the Madras State usually during April to June. Although the fry and later stages are readily available along the coasts, the adults are rarely met with. In the Java Sea, the eggs of *Chanos* have been obtained beyond 30 km. from the shore (Delsman, 1929), and the fry are caught along the coast when 2-3 weeks old (Schuster, 1949). Our knowledge of the spawning habits and movements of this fish is still meagre. The rôle played by the endocrine glands in the physiological behaviour of fishes is becoming increasingly clear from many recent investigations. Among the endocrines, the pituitary and the thyroid with their various hormones originating in particular regions and during definite periods are known to regulate reproduction, growth and behaviour and hence require close examination. As physiological changes are reflected in the histology of these glands a study of these organs in the normal fish was started before attempting to find out any correlation between the changes in the glands and the physiological state of the fish.

Several accounts of the structure and function of the teleost pituitary have been published and the earlier work has been reviewed by Charipper (1937). Subsequently, Woodman (1939) described the pituitary of the Atlantic Salmon. Buchmann (1940) followed the development and the histological changes of the hypophysis during all phases in the life cycle of the herring and observed that the hypophysis has a significance to the herring similar to that in the higher vertebrates. Kerr (1940, 1942a and b), after his studies on the histogenesis and morphology of the pituitary in teleosts, gave a basic plan of the pituitary with its variations in different species in relation to their systematic position. Bretschneider and Duyvené de Wit (1947) made a careful study of the cytological changes in the pituitary of *Rhodeus amarus* in relation to its reproductive cycle and found a regular alternation of acidophils and basophils in the anterior lobe.

An outstanding contribution to the study of thyroid in teleosts was made by Gudernatsch (1911) who compared the structure of this organ in several species. Harms (1929) observed an increase in the size of the thyroid gland in the Gobies and the Blennies during their migration from aquatic to amphibious environments. Eggert (1938) in his monograph on the morphology of the thyroid dealt with the histophysiology of the organ indicating the changes in structure during different phases of activity. Hoar (1939) showed a correlation between the functional condition of the thyroid gland and the activities of the Atlantic Salmon. Later, Hoar and Bell (1950) studied the thyroid of the Pacific Salmon during various

¹ Published with the permission of the Chief Research Officer, Central Marine Fisheries Research Station, Mandapam.

stages and different seasons and found heightened activity of the gland related particularly to increased metabolic work of osmoregulation in a fish prepared for life in salt water.

It is beyond the scope of this account to refer to the several experimental investigations on the endocrine physiology in fishes. The present state of our knowledge in the subject has been recently summarised by Hoar (1951).

MATERIAL AND METHODS.

The material included *Chanos* from 14 mm. the smallest size usually occurring along the coast, up to 550 mm. Total lengths have been given throughout in this paper. Those below 200 mm. were collected from the fry collecting centre at Chinnapalam creek and the Horseshoe Bay, Pamban, Gulf of Manaar (9° 16' N. and 79° 13' E.) during April-June, 1950 and 1951 and the larger ones were obtained during October, 1950 from the occasional catches by fishermen operating their nets within about five miles from the shore.

For routine preservation corrosive-formol was used and Bouin's fluid was also tried for comparison. The smaller fish were dropped in the fixative and later the heads alone were incised and left in the fixing fluid while in the larger fish the cranium was opened to expose as much of the brain as possible to ensure thorough penetration. Decalcification was avoided in most cases. Fairly successful sections were obtained after the major portion of the cranium was removed before sectioning. In materials decalcified with acids the basophilic cells of the pituitary were not properly stained. Longitudinal and transverse sections were taken at 5 or 7 micra thickness. Heidenhain's iron haematoxylin counterstained with eosin was used for general study of the histology and Mallory's aniline blue collagen stain was employed for identifying the different types of cells. The same technique was adopted for the study of thyroid also.

In describing the pituitary the nomenclature used by Kerr (1942a) has been followed.

STRUCTURE OF THE PITUITARY.

14-20 mm. fry: The earlier stages of the larva have not been obtained and hence the present account starts with the study of the pituitary in the smallest size of fry that are commonly collected along the coast. At this stage the pituitary is a small elongated organ suspended from the floor of the brain and is situated behind the optic chiasma. At the place where the pituitary is connected to the brain the thalamus is thin walled. The cavity of the third ventricle does not extend into the pituitary and is lined by ependyma cells. The pituitary measures about $325 \times 70 \times 50$ micra and is held on to the floor of the cranium by means of connective tissue fibres.

The whole organ is made up of two components, the nervous and the glandular, as in all teleost pituitaries. The nervous part is continuous with the floor of the midbrain and consists of a network of fibres and a few scattered nuclei. The glandular region which covers the nervous part is separated from the latter by a thin sheet of connective tissue.

Three regions can be distinguished in the glandular part even at this stage, an anterior, middle and posterior region (Fig. 1a). Of these, the anterior region shows a lumen which is in connection with the buccal cavity by means of an open duct arising from the roof of the mouth just in front of the branchial arches and sloping posteriorly towards the hypophysis. This fact has already been pointed out by the author (1951). This duct or canal is lined by a nearly flat epithelium with low cells and connective tissue layer beneath.

The glandular element of the pituitary in most teleosts is known to be derived from a solid inpushing of the buccal epithelium which extends below the brain.

This hypophysial stalk usually disappears in the early stages at about the time of hatching of the embryo (Haller, 1896; Mathews, 1939; and Kerr, 1940). Suchmann (1940) while studying the hypophysis of the herring observed the presence of an open hypophysial duct ('hypophysengang') connecting the hypophysis with the buccal cavity in the early stages of the larva before metamorphosis. The structure as found in *Chanos* closely resembles that described in the herring, but the duct in the present case remains open until the fish reaches about 53 mm. long. Further observations on the disappearance of this connection in the later stages are given below.

The anterior and middle regions of the hypophysis are more or less continuous, but they can be distinguished by the difference in the nature of the cells. In the anterior region the cells are nearly columnar with about 5 micra height and oval nuclei situated in the middle. The middle region consists of a mass of round or polygonal cells 5 micra in diameter and having round nuclei. In a transverse section through this region (Fig. 1c) the nervous lobe is found to extend into the middle. The posterior region consists mostly of nervous tissue in the centre with a peripheral layer of cells (Fig. 1d) with round nuclei and their cell walls are not

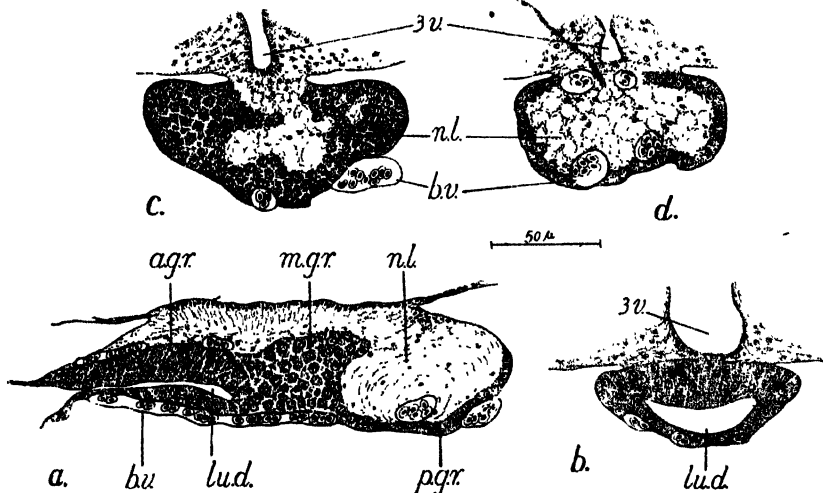


FIG. 1. a. Sagittal section of the pituitary of 14 mm. *Chanos*. b, c and d. Transverse sections through the anterior, middle and posterior regions respectively.

distinct. All the cells of the three different regions stain deep blue with Heidenhain's haematoxylin.

41-55 mm. stage: As the fry grows in length there is a general increase in the size of the hypophysis accompanied by significant changes. The whole organ measures about $590 \times 260 \times 160$ micra. There is great proliferation of cells in all the three regions, particularly on the dorsal side of the anterior region. As a result of multiplication of the cells the anterior region grows so as to cut off or enclose the cavity inside it. Simultaneously by further inpushings and growth of the cells more such cavities are produced. There is no regularity in the shape or size of these cavities and they are always empty. Fig. 2, a-e shows stages in the formation of the cavities in the anterior region. Side by side with these changes, the duct leading from the buccal cavity gets gradually constricted by about its middle resulting in the cessation of the connection between the hypophysis and the buccal cavity. The process is slow, starting when the fry grows to about 45 mm. and the connection is completely cut off when it reaches about 53 mm. in length. A vestige of this duct persists close to the anterior region of the hypophysis in the form of an

irregular space but it almost loses the cellular lining which is replaced by connective tissue. Even in later stages remnants of this space adjacent to the pituitary are noticeable.

The middle region does not show many changes. The nature of the cells remains the same but due to their growth towards the centre the small extension of the nervous lobe which was present in the early stages disappears. The posterior region continues to show a majority of the nervous tissue, but the cells in many places increase in numbers and grow in small groups towards the centre.

100–110 mm. stage: The pituitary at about this stage assumes a roughly rounded appearance and measures approximately $700 \times 500 \times 400$ micra. In a dissection of the pituitary from the ventral side of the cranium three transverse zones are distinguishable externally corresponding to the three regions of the gland. The anterior region is slightly less than half and is white in colour with meandering grooves on the surface, remotely resembling the human cerebellum. The middle

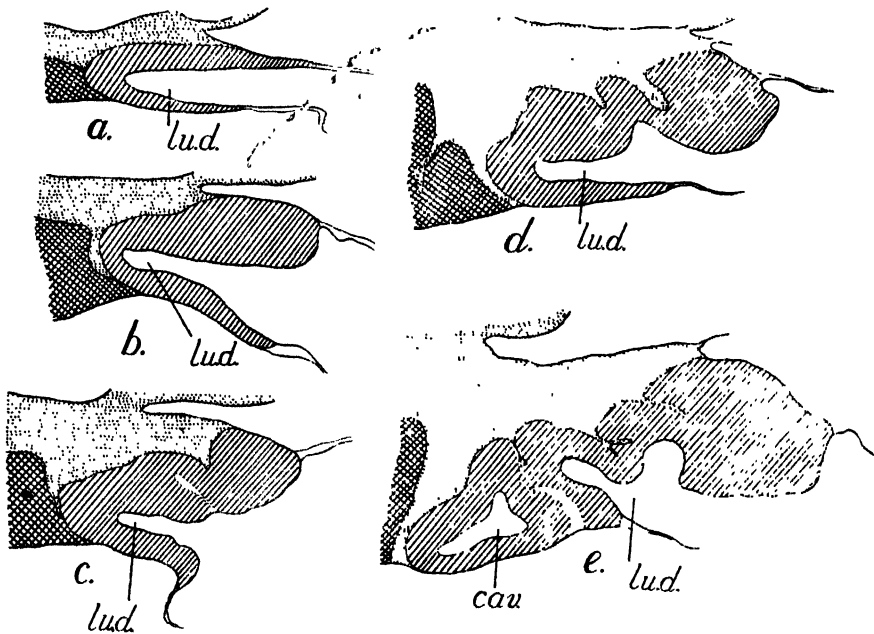


FIG. 2. *a-e.* Simplified camera lucida drawings of sagittal sections of the anterior region of the pituitary of the 14, 23, 30, 45 and 53 mm. fish showing successive stages in the formation of the cavities.

zone is very narrow and has a creamy yellow colour. The posterior zone is also as large as the anterior but it is white in colour and has a smooth surface unlike the first one. The whole gland is delicately suspended from the thalamus and is held in a depression in the floor of the cranium by strands of connective tissue.

In sections the anterior region shows an increase in the number of cavities than in the previous stage and a few in the process of formation by getting cut off from the outside. As pointed out before they have no definite size or shape. Each cavity is surrounded by a single layer of cells with an average height of 15 micra and acidophilic cytoplasm. Processes of the nervous lobe extend into the spaces among the cavities or vesicles, and between the nervous processes and cellular layer of the vesicles are seen a few blood capillaries. The middle region does not show any pronounced change. Although this region appears as a narrow one externally, towards the interior of the gland it widens to occupy roughly one-third

of the whole organ. Extensions of the nervous lobe are almost absent in this region. In the posterior region there is an increase in the cellular component and it shares the zone almost equally with the nervous part unlike in the earlier stages where the nervous lobe is greater in extent. The few cells turn out to be strongly acidophilic and exhibit a tendency to orient themselves towards the interior and adjacent to the nervous lobe.

200 mm. fish: Figure 3 shows a median sagittal section of the pituitary at this stage. It measures $1,100 \times 700 \times 500$ micra. The nervous lobe consists of an undivided network of neural fibres sloping in the form of processes towards the anterior and posterior ends of the gland. The processes of the anterior region are long and slender penetrating deeply among the vesicles while the major portion is disposed posteriorly. In the middle lobe of the gland, extensions of the nervous processes are at a minimum. The layer of collagenous or connective tissue seen between the glandular and neural component is no longer a continuous layer but a discontinuous sheet with breaks in several places. Ramifications of blood capillaries are seen in varying amounts in the different regions.

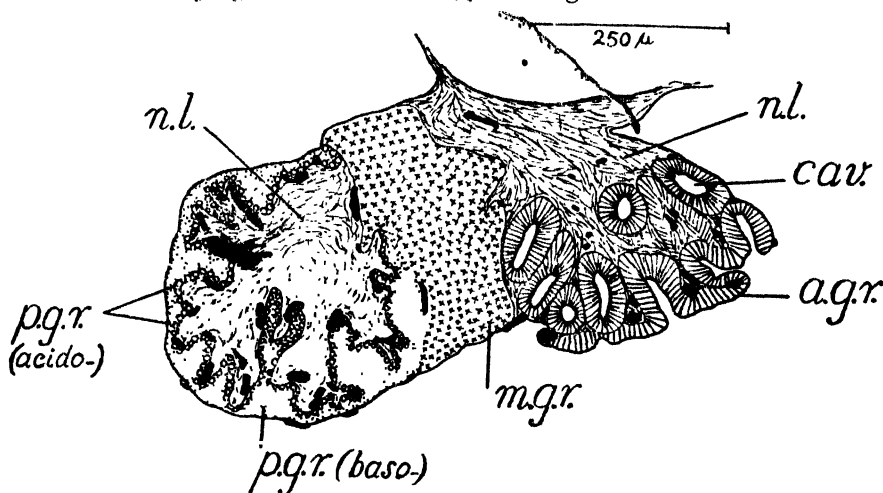


FIG. 3. Simplified camera lucida drawing of the sagittal section of the pituitary of 117 mm. fish indicating the distribution of the acidophils and basophils in the three regions.

The anterior glandular region: This is a relatively prominent region of the gland. Externally this region has an indented appearance mostly due to the presence of depressions on the surface forming vesicles. These may be large or small and irregular and are always empty. The epithelium of these vesicles consists of a single layer of cells (Pl. VII, Fig. 1) with an average height of 15 micra. The nuclei are round with a single nucleolus in each with scanty chromatin, situated near the end of the cell away from the lumen of the vesicle. All the cells are uniformly acidophilic. The cytoplasm is dense and finely granular towards the ends of the cells nearer the nervous lobe and it takes a bright red stain with acid fuchsin. Immediately close to this layer of cells is a network of capillaries surrounding the vesicles.

Cavities in the anterior lobe of the pituitary have been described in the herring by Buchmann (1940) and Kerr (1942b) in the trout. They have observed the presence of secretion (in the herring), or deep blue 'colloid' or detritus as in the trout *Salmo trutta* in these cavities. But such a condition has never been met with in the stages of *Chanos* and the cavities have been always found to be empty. While studying the histogenesis of the pituitary of the trout the formation of cavities in the anterior lobe of the gland has been noticed by Kerr (1940). He,

however, does not consider them as the remnants of a hypophysial cavity as seen in *Lepidosiren* (Kerr, 1933). Structurally the cavities in the pituitary of *Chanos* resemble those described in the herring and the trout, with the acidophils orientated round them, but it is not possible to compare their morphology in these different species.

The middle glandular region: This is a compact zone in the middle of the anterior and posterior regions, from which this is distinct although there is no septum or boundary separating the various regions. Unlike the condition in many other fishes, there is no mixing up of the cells with those of other regions as could be clearly marked in sagittal sections. It consists of close clusters of cells (Pl. VII, Fig. 2) without elaborate invasions of the nervous lobe processes. Capillary branchings are also relatively less in this region. The cells are small and well defined, with a diameter of 5 micra. All of them are acidophilic, staining deep brownish red with acid fuchsin or deep blue with iron haematoxylin. Thus this region differs from the corresponding lobe in the pituitary in the trout or the perch which even in early stages show acidophils, basophils and chromophobes.

The posterior glandular region: This region is characterised by the maximum invasion of the nervous lobe in the centre surrounded by the glandular cells. Unlike in the anterior lobe where the nerve processes are long and slender, in this region they are stout and blunt resulting in irregular indentations in the glandular region. An extensive branching of capillaries is also seen in the connective tissue boundary between the nervous and glandular lobes.

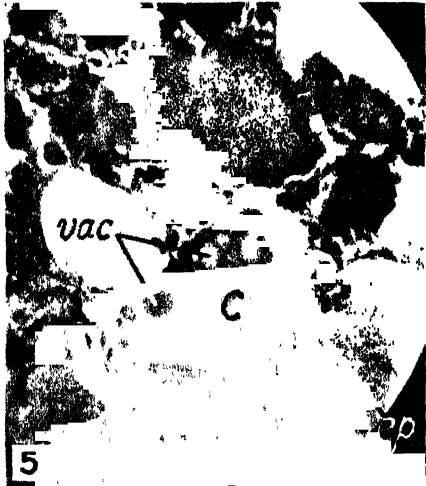
Two principal kinds of cells are found in the glandular region, the acidophils and the basophils, the former being the more common type. The distribution of the acidophils is very definite and seems to be typical. These are arranged more or less side by side regularly along the inner boundary and close to the nervous lobe and blood capillaries. In a sagittal section these appear like a continuous layer beneath which the basophils are situated. However, a few basophils may also occur among these acidophils. The acidophils are almost rounded with an average diameter of 7 micra. The chromophil substance of the cytoplasm stains brightly with acid dyes (Pl. VII, Fig. 3). The rest of the cells are dull basophils and take a light stain with basic stains. In appearance and in the arrangement of the cells this region resembles the middle lobe of the pituitary of *Perca fluviatilis* described by Kerr (1942a), except that in *Chanos* the extracellular acidophilic spheres mentioned by him are absent.

STRUCTURE OF THE THYROID.

14-20 mm. fry: The thyroid is a small racemose gland situated near the anterior end of the ventral aorta. The number of acini or follicles varies from 8 to 12 and their size is also not very definite. In one individual the smallest follicle measures 18 micra while the largest one is 78 micra along the longest diameter and the rest are of intermediate sizes. The whole gland is supported by a framework of connective tissue which is composed of a loose fibrous network containing numerous clear spaces representing the fat vacuoles of adipose cells. A system of vascular channels traverse the connective tissue. Irregular masses of pigment of yellowish brown colour are often seen embedded in the connective tissue of this region.

The follicles are lined by a single layer of epithelium and many of the follicles are connected together. There is no distinct basement membrane for the epithelium. The cells are nearly cuboidal and the cell walls are distinct. They have an average height of 7 micra and the nuclei are rounded, 3-4 micra in diameter with two prominent nucleoli in each nucleus. The cytoplasm is scanty and faintly vacuolated in appearance, particularly towards the inner ends of the cells.

The follicles have colloid within them which stains deeply with iron haematoxylin towards the periphery but lightly towards the centre. The colloid shows



specific affinity for acid stains. No vacuoles are seen in the colloid and the whole appearance of the gland suggests that it is in a quiescent state (Pl. VII, Fig. 4).

Groups of undifferentiated glandular cells without the formation of the colloid or any cavity in the centre are often met with in the follicles. These suggest that the later follicles are formed by proliferation of cells from the epithelium of older follicles as has been observed in the Atlantic Salmon (Hoar, 1939).

The histological condition of the thyroid in the 20 mm. fry is more or less similar to that seen in the 14 mm. fry. The number of follicles has increased and they have extended to the more posterior regions round the ventral aorta. The nature of the epithelial cells of the follicles remains unchanged, consisting of cuboidal cells with round nuclei, situated in the middle of the cells. Colloid is prominently observed in the follicles.

20-30 mm. fry: The gland has grown diffuse by the multiplication of the number of follicles whose size as well as shape vary; the largest one measuring 52 micra in diameter. The acidophilic colloid fills the follicles and the epithelial cells are cuboidal and without vacuoles, having an average height of 6 micra.

40-60 mm. fingerling: The glandular tissue has enlarged considerably spreading to the posterior regions with numerous follicles, the largest with a diameter of 60 micra. Acidophilic colloid is present in all the follicles. The cells of the epithelium are almost the same as in the previous stages. In one preparation, however, some of the cells showed one or two darkly staining large granules showing the same staining properties as the central colloid. Whether these represent newly formed colloidal material within the cells before it has moved to the lumen of the follicle or they are merely artefacts caused within the cells while preserving cannot be said at present.

100-120 mm. fish: Compared with the previous stages there is an increase in the number of follicles, most pronounced anteriorly and in the dorso-lateral portions of the ventral aorta. While the follicles are more closely packed in the anterior region, they are scattered posteriorly. A few are present in the ventral regions but they never extend to the caudal regions of the ventral aorta. In the regions where the follicles are crowded there is an engorgement of blood in the interfollicular spaces. The undifferentiated prefollicular tissue is seldom evident and histologically the thyroid acini are well separated. The follicles are nearly spherical but they vary much in size, the largest one encountered being 100 micra in diameter.

The epithelium is still cuboidal with cells of 4-5 micra in height and round nuclei occupying the middle of the cells. The colloid mass which completely fills the follicles is acidophilic in nature.

270 mm. fish: Here again there is a considerable increase in the bulk of the gland and an enlargement of the follicles. Fig. 4 shows the distribution of thyroid

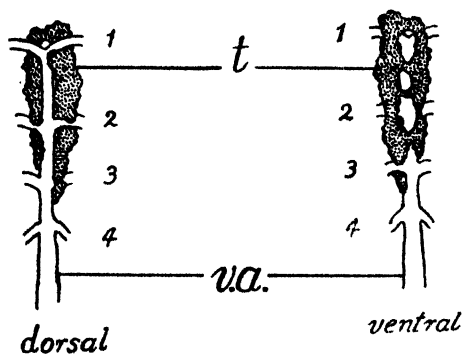


FIG. 4. The distribution of thyroid around the ventral aorta in a 240 mm. fish. 1-4 represent the branchial arches. $\times 3$.

material in a fish of 240 mm. length. Side by side with the development of the glandular component, there is great increase in the vascularization of the gland. The maximum size of the follicles at this stage is 110 micra. Many of the follicles have acidophilic colloid filling them while some of them are seen with large vacuoles in the periphery of the colloid (Pl. VII, Fig. 5). The epithelium is made up of cuboidal cells 4 micra in height with scanty cytoplasm and round nuclei.

550 mm. fish: This is the largest sized fish whose thyroid has been studied. Due to the enormous increase in the thyroid material and the well developed inter-follicular vascularization, the whole gland appears to be more organized as compared with the dispersion of the follicles of the earlier stages. The epithelial cells are always in close contact with the blood system of the interfollicular spaces.

The follicles are fully distended in most cases with colloid. They are thus considerably larger than those met with in the smaller fish. Follicles with a diameter of 150 micra are common at this stage. The epithelium, which may be described as squamous, consists of low cuboidal cells with an average height of 3 micra. The nuclei are slightly oval. The colloid ~~does~~ not seem to show the same degree of affinity to acid stains.

GENERAL CONSIDERATIONS.

The beginnings of histological differentiation in the pituitary at an early stage and the presence of colloid in the thyroid vesicles in the youngest fry captured along the coast would probably indicate that these glands have become functional in them. The early appearance of the acidophils of the anterior and posterior lobes is often associated with the general metabolism of the body, including growth (Kerr, 1939), while the appearance of the basophils in the middle lobe suggests a possible association of these cells with the maturation of gonads (Matthews, 1939). All the specimens examined for this study were juveniles in which the sexes could not be distinguished and this may explain the absence of basophils in the middle lobe in any of the stages described.

For distinguishing the various types of cells, the technique adopted by Kerr (1942a) has been followed here. The use of the terms 'acidophils' and 'basophils' has its limitations in view of the conflicting results obtained by different workers as regards the staining properties of the cells and cytoplasmic inclusions in the herring pituitary which were stained blue with Delafield's haematoxylin and red with Azan were basophils as opposed to the usual interpretation. A similar comparison between adjacent sections of *Fundulus* pituitary has been made by Grace E. Pickford (personal communication of unpublished observations) who has also come to the same conclusion.

Factors like food, season, condition of gonads and changes in the salinity of the environment are said to be responsible for variations in the histology of the thyroid. The *Chanos* larvae and young ones up to 200 mm. were collected from their natural surroundings in the shallow coastal regions during the summer months where the water had a salinity of 34‰ and the temperature varied from 25°C. to 32°C. in the course of twenty-four hours. The larger fish were caught within five miles from the shore where the salinity was about 34.5‰. All the stages of the fish examined here showed the thyroid follicles to be uniformly rounded with a low epithelium of nearly cuboidal cells and filled with acidophilic colloid, thereby suggesting a resting condition. Due to the budding of the follicles and enlargement in their size, the bulk of the thyroid material increases and grows more around the caudal regions of the ventral aorta. The colloid is formed even in the larvae and is retained within the follicle throughout. Withdrawal of the colloid has not been observed except in a single instance of a 270 mm. fish but the structure of the gland in the larger fish did not suggest having undergone any involution. In the metamorphosing herring Buchmann (1940) observed a great increase in the height

of the thyroid epithelium and presence of vacuoles in the chromophilic colloid. Pronounced histological changes were not noticed in *Chanos chanos* larvae of 14–20 mm. size. Similarly no significant changes in the gland were seen in any of the later stages. Perhaps the changes in the environment are not very marked to alter the state of the gland. These points, however, remain for future study.

SUMMARY.

A histological account of the pituitary and thyroid of the early stages of *Chanos chanos* is given.

A connection between the buccal cavity and the anterior region of the pituitary is observed in fish up to 55 mm. length. Changes in the nature of the cells in the anterior, middle and posterior glandular regions take place gradually so that in the later stages the anterior and middle lobes consist of acidophilic cells while both acido- and basophils are present in the posterior lobe.

The thyroid increases in bulk as the fish grows, but under normal environmental conditions the gland does not show any marked degree of activity.

ACKNOWLEDGEMENTS.

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EXPLANATION OF PHOTOMICROGRAPHS.

PLATE VII.

- FIG. 1. Anterior glandular region of the pituitary of a 200 mm. *Chanos* showing the acidophils arranged round the cavities. $\times 500$.
 2. Middle glandular region with only acidophils. $\times 500$.
 3. Posterior glandular region showing the acidophils orientated along the boundary near the nervous lobe. $\times 500$.
 4. Thyroid follicles in a 14 mm. fry. $\times 500$.
 5. Thyroid in a 270 mm. fish, with vacuoles in some of the follicles. $\times 250$.

KEY TO LETTERING.

<i>acido</i>	.. Acidophils.
<i>a.g.r.</i>	.. Anterior glandular region.
<i>b.v.</i>	.. Blood vessel.
<i>baso</i>	.. Basophils.
<i>c.</i>	.. Colloid.
<i>cav.</i>	.. Cavity of the anterior region.
<i>ep.</i>	.. Epithelium of the thyroid follicle.
<i>lu.d.</i>	.. Lumen in continuation with the hypophyseal duct.
<i>m.g.r.</i>	.. Middle glandular region.
<i>n.l.</i>	.. Nervous lobe.
<i>v.a.</i>	.. Ventral aorta.
<i>vac.</i>	.. Vacuoles.
<i>3v.</i>	.. 3rd Ventricle.

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OBSERVATIONS ON THE PHYSICAL AND BIOLOGICAL FEATURES OF THE INSHORE SEA BOTTOM ALONG THE MALABAR COAST ¹

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1. INTRODUCTION.

The features of the sea bottom—physico-chemical as well as biological—form aspects of the environment of marine fishes which have long been recognized as important in any programme of comprehensive research on fisheries. Since Petersen's construction (Petersen and Boysen Jensen, 1911) of the now well known grab sampler which he used for extensive quantitative surveys of the sea bottom in Danish waters, several workers have carried out studies in different parts of the world, using this sampler in one form or another either by itself or in combination with other devices like the dredge and the trawl. Investigations on the fauna of the inshore sea bottom of the Malabar Coast were taken up as part of the programme of the Calicut Sub-Station of the Central Marine Fisheries Research Station, with the aim of (1) obtaining the necessary general picture of the environment, (2) understanding the qualitative and quantitative variations in the distribution of the fauna in the fishing grounds during different periods of the year, and their possible relationship with the fishery of the Malabar sole, *Cynoglossus semifasciatus*, a bottom food fish of considerable commercial importance on this coast, and (3) assessing ultimately, the exact part played by the different species and by the bottom fauna as a whole in fish-food production.

The part of the sea in the immediate neighbourhood of West Hill (Calicut) was selected for intensive study as it was conveniently near the Research Station and was also considered more or less typical of the Malabar Coast in its general features. No quantitative survey of this type has been attempted in Indian waters before and the only previous work that may be cited in this connection is that of Samuel (1944) who, using the naturalists' dredge, studied the fauna of the level sea bottom at Madras to examine the animal communities and was able to recognize three of them depending on whether the bottom material was pure sand, pure clay or a mixture of both.

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2. THE GENERAL FEATURES OF THE MALABAR COAST.

The Malabar Coast which is more or less straight without any large bays, is characterized by a number of short rivers joining the sea after running through the comparatively narrow belt of low land separating the sea from the Western Ghats. The plains over which these rivers flow consist geologically of laterite formation fringed on the seaward side by a narrow belt of recent alluvium (Bristow, 1938). These rivers discharge into the sea every year immense volumes of water which must bring with it large quantities of organic and inorganic substances collected along its course.

The shore along this coast is mainly sandy but there are some low cliffs or reefs of laterite here and there, as at Cannanore, Tellicherry, Elathur and Beypore. The submerged sea bottom is predominantly muddy and devoid of weeds with very few rocky and sandy patches. Hornell (1908) states: 'With a few unimportant exceptions the bottom from about a mile from the shore out to 30 fathoms from Ponnani northwards to Mangalore is composed of soft dark grey mud with small dead shells, chiefly bivalves, more or less sparsely distributed through it. As a rule the sedentary fauna of this area outside the 10 fathom line is extremely scanty . . . and algae are of course entirely absent'.

A special feature of the Malabar and Cochin inshore sea bottom as distinct from other mud bottoms is the presence of what are called '*mud banks*' scattered at various places along the coast, e.g. Alleppey, Narakal, Calicut, Quilandi, Pantalayani, Beypore, Munambam, Chellanam and off Cochin (Du Cane, Bristow, Brown and Keen, 1938). These have been known for a very long time as areas where the sea remains calm even when the roughest weather prevails and the water is very rough in the neighbouring areas. The fine mud of such banks is in an unconsolidated state and the banks themselves have been known to shift from place to place now and then. The physical properties of one such bank near Cochin were the subject of investigation by a committee of experts in 1938. A great agitation of the bottom mud was noticed during the rough weather season in many parts along the coast during the years 1949 and 1950 and judging from the regularity of the South-West monsoon here, such an agitation seems to occur every year though variable in intensity and extent.

Climatically, Malabar has four distinct periods in the year. From June to the beginning of September is the characteristic South-West monsoon season with strong westerly winds, rough weather and heavy surf on the seashore. There is heavy rainfall, especially in June and July. September and October constitute a transitional period with a fairly dry weather but occasional rains. Next comes the cool North-East monsoon period from November to February (inclusive), with land winds and a calm sea. In February the wind veers to the north and from March to May (inclusive) come the hot, dry months with continued calm sea and light breezes from the north-west and north north-west. By the end of May transitional conditions set in and in June the South-West monsoon is in full swing again.

3. PHYSICAL AND HYDROGRAPHICAL FEATURES OF THE AREA SELECTED FOR INTENSIVE STUDIES.

(a) *Physical features*: West Hill (Calicut) lies approximately in the Latitude $11^{\circ} 17' \text{ N.}$ and Longitude $75^{\circ} 46' \text{ E.}$ and the region selected was in its immediate

neighbourhood extending from the shore down to the 10 fathom line and covering an area of about 10 square miles. In rainfall Calicut is more or less typical of coastal Malabar with an annual normal of 121 inches; during the year 1950 the total rainfall was 128.9 inches nearly half of which fell during the months of June and July. Fig. 1 shows the contour of the coastline in the region and the positions of the 3, 5,

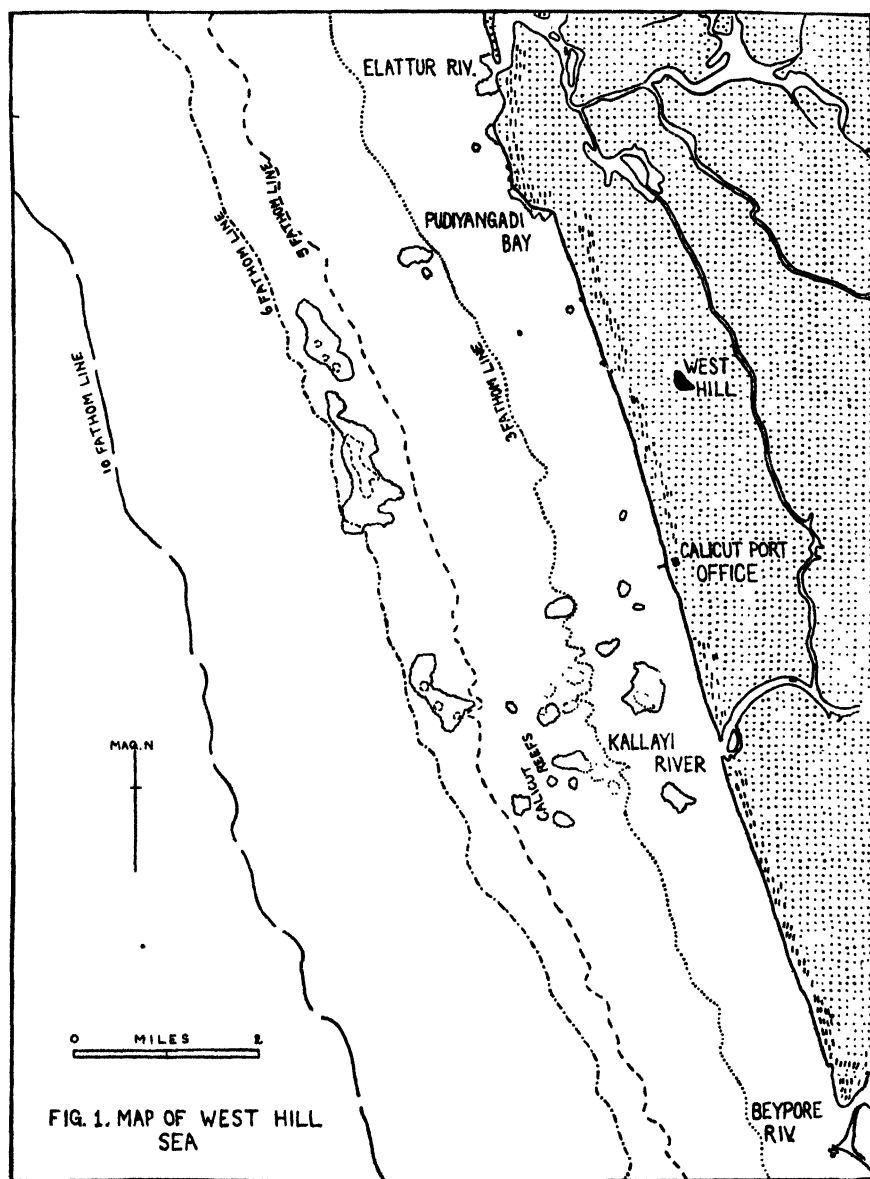


FIG. 1. MAP OF WEST HILL SEA

6 and 10 fathom lines as shown in the Admiralty Chart. The West Hill sea is subject to the influence of three considerably large rivers namely the Elathur river, the Kallayi river and the Beypore river entering the sea at about 5 miles north, 5 miles south and 10 miles south of West Hill respectively. The shore is throughout sandy, some cliffs of rock occurring only near Elathur. Just about the Low

Water Spring level the coarse sand gives place to a mixture of fine sand and mud and a few yards further down, to soft fine mud of the type found over the rest of the submerged bottom. Between the 5 and 6 fathom lines due west of West Hill there is a patch of rocky ground which in some places rises a short distance above the bottom level.

A mud bank of the type mentioned in the previous chapter has been known to occur near Calicut and seems to have shifted to the West Hill area during the course of the present investigations, but its actual extent is not known with any definiteness.

(b) *Sea Temperature*: Chidambaram (1950) gives the mean surface temperatures of the sea at West Hill for different months of the year taken over a period of 11 years from 1932-33 to 1942-43. Records of surface temperature, salinity and pH as well as the bottom salinity taken periodically at the 8 fathom zone have been maintained from 1948 onwards in the Central Marine Fisheries Research Sub-Station, and from these are derived the monthly mean temperatures for the period December, 1949 to November, 1950, shown in Table I in comparison with Chidambaram's figures. There is a slight difference between the two sets of values, the present ones being slightly lower throughout, but there is general agreement in the seasonal trends. It is seen that the lowest temperature is recorded in July, the months of June to September (inclusive) standing out as the months of low values and that the highest temperature was recorded in April, the months of March to May (inclusive) standing out as the months of high values. The year of the present investigations thus appears to have been normal in this respect.

(c) *Salinity and pH*: Table II shows for the period December to November the monthly mean values and the monthly range of variation of the periodical salinity readings for the surface and the bottom samples of seawater at West Hill taken at the 8 fathom region.

March, April and May were the months of high surface salinity, the highest being in April. The monsoon months gave very low mean values the lowest being in August ($26.90/_{00}$), though the lowest values for individual observations was noticed in July when the extreme values were $16.13/_{00}$ and $34.03/_{00}$. The months of widest variation were July and August and of the least variation were January, February and March.

TABLE I.

Monthly average surface temperature of the seawater at West Hill (Calicut).

Months.	Average for 11 years (Chidambaram, 1950).	Average during Dec., 1949-Nov., 1950.	Extreme values during Dec., 1949-Nov., 1950.
December ..	28.29	27.57	27.0-28.3
January ..	28.14	27.41	26.7-27.9
February ..	28.66	28.0	27.2-28.5
March ..	29.98	29.28	28.5-29.8
April ..	30.31	29.96	29.5-30.4
May ..	30.12	29.0	27.2-30.1
June ..	27.27	26.85	25.3-28.8
July ..	25.91	24.87	23.2-25.7
August ..	26.37	25.08	23.4-27.0
September ..	26.67	25.16	23.7-27.9
October ..	28.18	27.25	26.2-28.4
November ..	28.52	27.98	26.6-28.9

While the bottom salinity showed much less variation than the surface salinity, the effects of the seasons could still be seen in its values also. Its maximum range was in June (31.16 to $35.02/_{00}$). The mean value was highest in April ($36.15/_{00}$)

and dropped down to 35.36‰ in May, 33.86‰ in June and 33.71‰ in July. There was a gradual rise from August onwards with a slight drop in October.

The salinity of the water collected a few yards away from the shore was also determined for the months of August to November, 1950 and the values are shown in the same Table.

TABLE II.

Salinity of seawater at West Hill (Calicut) during the period December, 1949 to November, 1950.

Months.	Surface salinity (8 fathom region).		Bottom salinity (8 fathoms).		Salinity of shore water.	
	Mean.	Extremes.	Mean.	Extremes.	Mean.	Extremes.
December	34.42	33.45-35.23	34.55	33.8-35.4	..	..
January	33.91	33.5-34.26	33.83	33.6-34.24	..	..
February	34.12	33.8-34.23	34.03	33.8-34.15	..	..
March	35.42	34.9-35.77	35.47	35.2-35.8	..	..
April	36.06	35.1-37.0	36.15	35.4-36.9	..	..
May	35.05	31.3-36.1	35.36	33.3-36.3	..	..
June	31.63	28.62-33.85	33.86	31.16-35.02	..	..
July	27.55	16.13-34.03	33.71	32.8-35.1	..	..
August	26.9	19.06-34.81	34.36	33.63-34.9	28.58	20.87-33.21
September	32.43	28.15-35.03	34.7	33.43-35.23	31.93	30.4-34.0
October	31.02	25.97-33.83	34.14	33.23-35.0	31.16	28.05-33.83
November	34.06	31.97-35.0	34.93	34.23-35.6	32.78	27.65-34.23

Table III shows the range of pH values for the period of the quantitative investigations under review. June, July and August are seen to be the months of lowest pH values. The transition to these values from the pre-monsoon high values is seen to be sudden.

TABLE III.

Range of pH values of the surface seawater (8 fathom region) at West Hill (Calicut) for the period December, 1949 to November, 1950.

Months.	pH range.	Months.	pH range.
December	8.4-8.6	June	8.0-8.2
January	8.3-8.5	July	7.9-8.2
February	8.35-8.6	August	7.9-8.3
March	8.35-8.5	September	8.3 (3 readings only).
April	8.4-8.6	October	8.2-8.5
May	8.4-8.6	November	8.4-8.5

4. METHODS.

Quantitative samples were taken in a locally made light grab sampler of the Petersen type weighing about 30 lbs. and scooping an area 40 cm. by 25 cm. (0.1 m.²). As the bottom mud was throughout fine and soft this light grab was always able to cut through the bottom very easily and to come up thoroughly filled in with the mud. As the samples had to be taken in an ordinary dug-out canoe and the hauling done manually, the lightness of the apparatus was a great advantage.

The quantitative data treated here refer to the period December, 1949 to November, 1950 (inclusive) thus covering one full year. But along with these

are also considered some qualitative data collected by examination of dredge samples, taken on a few occasions in April, 1949 and periodically from July to October, 1949, as well as information collected in October-November, 1949 from experimental samples obtained with the grab-sampler which was then under trial.

The qualitative samples mentioned above were obtained from the fishing grounds between the Low Water Level and the 4 fathom zone. The quantitative grab samples were taken at regular intervals of depth along three imaginary transects running about half a mile apart from the shore seaward. The depths at first chosen were 4 fathoms, 10 fathoms and just below the Low Water Level; but from January, 1950, the 2, 8 and 6 fathom regions were also added on. As the slope of the sea-bottom was gradual, the horizontal distance between successive levels was more or less the same, and the stations were thus equidistant. No special equipment was used for fixing the stations, and they were reached each time by taking frequent soundings of depth, and keeping along the transect—which was necessarily quite wide (about half-a-mile)—, by sighting certain known landmarks. It may be assumed that no two samples—at least successive ones—were obtained in one and the same 0.1 m.² area, and also that the samples were never so far away from one another as to make the results of the different weeks uncomparable.

Each of the depths mentioned was sampled once in a fortnight (January, 1950 to third week of June, 1950) or a week (the remaining period), three samples being taken each time, one along each transect. The material was pooled together and screened through a 0.5 mm. mesh sieve and sievings were brought to the laboratory with the animals alive. After qualitative examination the animals were preserved in weak formalin and taken out later on for weighing and counting. The total rough wet weights of the animals of each pooled sample was determined after removing as much fluid as possible from the killed animals with the use of a blotting paper. Whenever the samples were too large or had much fine foreign material to be carefully eliminated before the weights could be taken, a good fraction (by weight) was taken, cleaned and reweighed, this latter weight being used for estimating the total weight. Animals with hard shells were negligible in the shallower levels and where they were large as in the case of *Pholas orientalis* at 4 and 6 fathoms, the shell weight has also been determined separately. In the 8 and 10 fathom regions where small gastropods and very tiny Lamellibranchs were frequent, the soft animals and the others were weighed separately. No attempt has been made to determine the dry organic weight.

The fractional method was used for counting also, whenever the samples were too large for counting as a whole.

The present sampling method differs from the customary method used in bottom fauna investigations mainly in that the samples are not all taken within a brief period of time in one or more seasons of the year, but spread over the entire year. It has consequently the defect of limiting the degree of accuracy of any estimation of the 'stock of the moment' (Blegvad, 1930) as the different samples in any series that may be taken into account in such an estimation would be considerably separated in time. Monthly and seasonal averages can, however, be calculated reliably and the method has the advantage of permitting a continuous and close observation of the cycle of events—physical as well as biological—in the bottom environment.

5. RESULTS.

(a) *Dredge and Grab collections during the period from July, 1949 to November, 1949:* The results of the qualitative examination of the dredge and grab collections made during the months of July to November, 1949 are summarized in Table IV. *Cynoglossus semifasciatus* though really a bottom species, was at no time captured in the gear used in these investigations and hence does not find a place in the Tables.

TABLE IV.
Animal contents of the Qualitative Samples taken from July to November, 1949.

(*p* and *a* indicate present and abundant respectively; blank space indicates absence of the species).

Months.	July.	August.	September.	October.	November.
Total number of samples ..	11	12	6	20	24
Gear used ..	Dredge ..	Dredge ..	Dredge ..	Dredge for 6 & grab for 14 samples.*	Grab only.*
Depth ..	1, 1½, 2 and 3 fms.	L.W.M. to 2 fms.	2 fms.	L.W.M. to 2 fms.	L.W.M. to 4 fms.
1. <i>Prionospio pinnata</i> ..			<i>p a</i> *	<i>p a</i> young ones	<i>p a</i> dominant.
2. <i>Sternaspis scutata</i> ..			<i>p</i> *	<i>p</i> young ones	<i>p</i>
3. Other polychaetes ..			<i>p</i>	<i>p</i> in dredge only	<i>p</i>
4. <i>Cavernularia</i> sp. ..	<i>p</i>	<i>p</i>	<i>p</i>	<i>p</i> in dredges only	
5. <i>Lucina vesicula</i> ..		<i>p</i>	<i>p</i>	<i>p</i>	<i>p</i>
6. <i>Theora opalina</i> ..	<i>p</i>	<i>p</i>	<i>p</i>	<i>p</i> in dredge only	
7. <i>Metapenaeus affinis</i> ..				(5.10-1949).	
8. Other prawns ..	<i>p</i>				
9. <i>Diogenes</i> sp. ..		<i>p</i>			
10. <i>Matuta victor</i> ..		<i>p</i>			
11. <i>Cheiriphotis megacheles</i> ..		<i>p</i>	<i>p</i>	<i>p</i>	<i>p</i>
12. <i>Triptacumen vagina</i> ..	<i>p</i>	<i>p</i>	<i>p</i>	<i>p</i> in dredge only	
13. <i>Solea ovata</i> ..		<i>p</i>	<i>p</i>	<i>p</i>	
14. <i>Tetradon</i> sp. ..	<i>p</i>	<i>p</i>	<i>p a</i>	<i>p</i> on 5.10.1949 only	<i>p</i>
15. <i>Nemeritis</i> species ..	<i>p</i>				
16. Egg masses of Cuttlefish.					
Remarks ..	7 of the samples (taken on 6th, 19th, 26th and 28th) had no animals at all.	5 samples taken on 2-8.1949 between L.W.M. & 4 fms. had no animals.	*Newly settled and very young; first noticed on 7-9.1949	*Dredge used till 14.10.1949 & grab thereafter.	*Exploratory quantitative hauls.

Until September the bottom fauna was extremely poor and there were practically no animals to constitute an infauna, several of the samples showing no animals of any kind at all after the material was washed through a sieve of 0.5 mm. mesh. Such absence of animals could not be ascribed to deficiencies in the sampling method. Occasionally however, individuals of *Cavernularia* sp., *Lucina vesicula*, *Theora opalina* (only once before September), and a Nemertine species made their appearance in the collections. The few other forms that occurred very occasionally included *Solea ovata*, *Tetrodon* sp., *Trypauchen vagina* and *Metapenaeus* spp. During the first half of September, polychaetes—dominated by *Prionospio pinnata*—began recolonizing the area, and by the middle of November a rich infauna had developed in the shallow area of the sea bottom forming a belt along the shore. This belt was made up largely of polychaetes but its shoreward margin—the zone of fine mud mixed with some fine particles of sand—was dominated by species of *Phoronis* and *Polydora*.

It seems probable that a fairly dense fauna existed in the shallow area during April, 1949 also, but the samples examined in that month (trial hauls with the dredge) were all taken from the 4 fathom zone (which proved to be the poorest in fauna during the entire period of these investigations) and these indicated a very poor fauna, some of them showing no animals at all and others showing just a small number of polychaetes and small hermit crabs (*Diogenes* sp.). In the sand between the Low Water Neap and Spring levels, however, there was a very rich population of *Donax cuneatus* and *Emerita asiatica* until they were destroyed completely in the monsoon season that followed, when there was a great agitation of the inshore sea bottom. It may be mentioned here that these species completely failed to recolonize the West Hill sands during the succeeding seasons and that only in October-November, 1950, were they seen again to have successfully settled down here.

(b) *Results of Grab Samples during the period December, 1949 to November, 1950:*

1. *Nature and distribution of the members of the fauna at different levels during the different seasons.* It is not proposed in this paper to enter into details regarding the ecology of individual species. The main features of the fauna at the different levels during the different seasons, as judged by an analysis of the more common elements will be given below. The occurrence of the common forms during the different months of the year, and at different levels of the sea bottom respectively has been summarized in Tables V and VI.

During the season of commencement of the quantitative studies the inshore sea bottom had a fauna as mentioned above, with a specially rich belt in the shallow region dominated by polychaetes chief of which was *Prionospio pinnata*. The densest population was found at two fathoms and just below the Low Water Level. The other important animals of this zone were *Phoronis* sp. (dominant near the Low Water Level) and *Polydora* sp., *Glycera alba*? and certain other polychaete species of the syllid, Nereid and Terebellid groups and the Amphipod *Cheiriphotis megacheles* were also occurring frequently. The forms that occurred occasionally, included small individuals of *Modiolus undulatus*, *Theora opalina*, *Meretrix casta*, *Siliqua radiata*, *Arca* (*Scapharca*) *gubernaculum*?, *Diopatra variabilis*, *Pectinaria* (*Amphiclene*) *Crassa*, *Lumbriconereis latreilli* and a large Nemertine species. The four fathom zone was very poor both in the number of individuals and in the number of species and on several occasions there were no animals at all noticeable in the collections from this region. Some patches of *Pholas orientalis* were discovered in the 4 and 6 fathom regions during February but the form occurred only in two collections. From six to ten fathoms there was a change in the composition of the fauna though the species as well as individuals remained numerically small and some species such as *Prionospio pinnata*, *Lumbriconereis latreilli*, *Sternaspis scutata* and *Cheiriphotis megacheles* were common to all the depths. The samples from this region were distinct by the fact that the material left on the 0.5 mm. mesh.

TABLE V.

Occurrence of some of the Bottom Animals in the West Hill Sea during different months of the period December, 1949 to November, 1950.
(All levels have been taken together; p indicates presence and blank space indicates absence of species).

Months.	Dec. 1949	Jan. 1950	Feb. 1950	Mar. 1950	Apr. 1950	May 1950	June 1950	July 1950	Aug. 1950	Sept. 1950	Oct. 1950	Nov. 1950
1. <i>Prionospio pinnata</i> ..	p	p	p	p	p	p	p	p	p	p	p	p
2. <i>Sternaeopsis scutata</i> ..	p	p	p	p	p	p	p	p	p	p	p	p
3. <i>Lumbriconereis latreilli</i> ..	?	p	p	?	p	p	p	p	p	p	p	p
4. <i>Diopatra variabilis</i> ..			p	p	p	p	p	p	p	p	p	p
5. <i>Olymene</i> sp. ..	?	p	p	p	p	p	p	p	p	p	p	p
6. <i>Pectinaria</i> (<i>Amphictene</i>) <i>Crassa</i> ..	p	?	p	p	p	p	p					
7. <i>Sabellaria spinulosa</i> ..												
8. <i>Polydora</i> sp. ..	p	p		?	p	p	p	p	p	p		p
9. <i>Phyllochaetopterus</i> sp. ..			p	p	p	p	p	p	p	p	p	p
10. <i>Phoronis</i> sp. ..	p	p	p	p	p	p	p	p	p	p	p	p
11. <i>Nemeritis</i> species ..	p			p	p	p	p	p	p	p	p	p
12. <i>Pholas orientalis</i> ..			p	p	p	p	p	p	p	p	p	p
13. <i>Nuculid</i> species ? ..			?	p	p	p	p	p	p	p	p	p
14. <i>Lucina vesicula</i> ..				p	p	p	p	p	p	p	p	p
15. <i>Theora opalina</i> ..			p	p	p	p	p	p	p	p	p	p
16. <i>Siliqua radiata</i> ..	p	p			p	p	p					
17. <i>Modiolus undulatus</i> ..	p	p			p	p	p					
18. <i>Meretrix casta</i> ..			p	p	p	p	p					
19. <i>Acteocina Townsendi</i> ..				p	p	p	p	p	p	p	p	p
20. <i>Turricula javana</i> ..				p	p	p	p	p	p	p	p	p
21. Small ophiuroids ..		p	p	p	p	p	p	p	p	p	p	p
22. <i>Cheiriphotis megacheles</i> ..			p	p	p	p	p	p	p	p	p	p
23. <i>Alpheus malabaricus</i> ? ..	p	p	p	p	p	p	p	p	p	p	p	p
24. <i>Pycnogonids</i> ..		p	p	p	p	p	p	p	p	p	p	p

I am indebted to Dr. H. C. Ray of the Zoological Survey of India for help in the identification of some of the Molluscs mentioned in this work.

TABLE VI.

Vertical Distribution of some of the Bottom Animals of the West Hill Sea during the period December, 1949 to November, 1950.

(All months have been taken together; *p* indicates presence and blank space indicates absence of species.)

Levels.	↓ L.W.M.	2 fms.	4 fms.	6 fms.	8 fms.	10 fms.
1. <i>Prionospio pinnata</i> ..	<i>p</i>	<i>p</i>	<i>p</i>	<i>p</i>	<i>p</i>	<i>p</i>
2. <i>Sternaspis scutata</i> ..	<i>p</i>	<i>p</i>		<i>p</i>	<i>p</i>	<i>p</i>
3. <i>Lumbriconereis latreilli</i> ..	<i>p</i>	<i>p</i>	<i>p</i>	<i>p</i>	<i>p</i>	<i>p</i>
4. <i>Diopatra variabilis</i> ..	<i>p</i>	<i>p</i>		<i>p</i>	<i>p</i>	
5. <i>Clymene</i> sp. ..				<i>p</i>	<i>p</i>	<i>p</i>
6. <i>Pectinaria (Amphictene) Crassa</i>		<i>p</i>		<i>p</i>	<i>p</i>	<i>p</i>
7. <i>Sabellaria spinulosa</i> ..				<i>p</i>		<i>p</i>
8. <i>Polydora</i> sp. ..	<i>p</i>	<i>p</i>				
9. <i>Phyllochaetopterus</i> sp. ..				<i>p</i>	<i>p</i>	<i>p</i>
10. <i>Phoronis</i> sp. ..	<i>p</i>	<i>p</i>				
11. <i>Nemertine species</i> ..	<i>p</i>	<i>p</i>	<i>p</i>	<i>p</i>	?	<i>p</i>
12. <i>Pholas orientalis</i> ..			<i>p</i>	<i>p</i>		
13. Nuculid species ? ..				<i>p</i>	<i>p</i>	<i>p</i>
14. <i>Lucina vesicula</i> ..				<i>p</i>	<i>p</i>	<i>p</i>
15. <i>Theora opalina</i> ..	<i>p</i>	<i>p</i>				
16. <i>Siliqua radiata</i> ..	<i>p</i>	<i>p</i>				
17. <i>Modiolus undulatus</i> ..	<i>p</i>	<i>p</i>		<i>p</i>		
18. <i>Meretrix casta</i> ..	<i>p</i>	<i>p</i>				
19. <i>Acteocina Townsendi</i> ..	<i>p</i>	<i>p</i>	<i>p</i>	<i>p</i>	?	<i>p</i>
20. <i>Turricula javana</i> ..					<i>p</i>	<i>p</i>
21. Small Ophiuroids ..				<i>p</i>	<i>p</i>	<i>p</i>
22. <i>Cheiriphotis megacheles</i> ..	<i>p</i>	<i>p</i>	<i>p</i>	<i>p</i>	<i>p</i>	<i>p</i>
23. <i>Alpheus malabaricus</i> ? ..	<i>p</i>	<i>p</i>				
24. Pycnogonids ..				<i>p</i>	<i>p</i>	<i>p</i>

sieve after washing away the finer material was always dominated by fine shining Lamellibranch shell pieces, empty gastropod shells such as those of *Turritella*, *Turricula*, *Nassa* and *Umbonium* species and tubes of Maldanid polychaetes. *Clymene* sp. was common in these samples and this and a minute Nuculid (?) bivalve were characteristic animals of the deeper levels during the subsequent months. From January onwards some Pycnogonids and a few small ophiuroids were also found now and then in this region. There was thus a clear zonation in the vertical distribution of the organisms among different depths of the sea bottom, the deeper zone and the shallower zone being separated by the 4 fathom region which had a poor population of animals. This kind of differentiation existed in all the seasons of the year. Table VI gives some idea of the general zonation taking the whole year into account for the purpose of assigning limits for the vertical distribution of the different animals.

During the hot dry season (March, April and May) the fauna of the shallower region remained more or less the same in composition although there was some gradual decline in the density of the dominant species and a few disappeared altogether (see Table V). *Prionospio* was absent in the 10 fathom region during all the three months and in the 8 fathom region after March. The 4 fathom region remained poor but the deeper levels recorded an increase and animals of Nuculid (?) species, *Turricula javana*, and *Phyllochaetopterus* sp. made their appearance in the collections regularly. The individuals of the Nuculid (?) species, were extremely minute and though they occurred consistently in large numbers during the latter part of the season (the number more or less gradually increasing from March onwards and reaching a figure of 8,900 per m.² on the 26th of May) their mass was

almost negligible on account of their extremely minute size. *Pholas orientalis* occurred only in one collection during the season, namely on the 10th April in the 6 fathom sample. This is a species with a very uneven distribution.

In the South-West monsoon months the inshore bottom animals suffered a severe decline and in the shallower levels—4 fathoms inward—there was a sudden and almost total disappearance of all macroscopic bottom animals. *Prionospio* and *Phoronis* disappeared completely, only a few bits of the latter (without the tubes) occurring now and then till July and the former not occurring at all after the first week of June. The mud-goby *Trypauchen vagina* began to appear frequently in the West Hill inshore area after the commencement of the rainy season. In the deeper levels, Ophiuroids and Chaetopterids completely disappeared and only the Maldanid *Clymene*, the Nuculid (?) species and *Lumbriconereis* continued throughout. Occasional members of this region during the season included *Sterna sp. scutata*, *Nephtys* sp., *Dentalium* sp., *Turricula javana*, *Nassa* sp., *Acteocina Townsendi*, *Oliva* sp., and *Lucina vesicula*.

The recolonization of the shallower region started when the post-monsoon conditions were established in the sea but was slow and unsteady. Various species of polychaetes, again dominated by *Prionospio pinnata* started settling in September, the young ones kept on fluctuating in numbers at a low level during the succeeding weeks, and by the end of November, the population had not yet reached any considerable density as compared with the corresponding period of the previous year. The only Lamellibranch forms that had settled during the season as could be seen from grab samples were *Pholas orientalis*, *Theora opalina* and *Siliqua radiata*. The first of these was fairly common but the latter two were rather rare. Nuculid (?) bivalves in the 8 and 10 fathom region showed a large decline in numbers during the latter half of the season. *Clymene* sp., *Lucina vesicula* and *Lumbriconereis latreilli* were the commonest components of the fauna of this region during this season.

2. *Total wet weights of animals.* The result of estimations of the total wet weights of the animal contents of the grab samples studied during the period from different levels of the sea bottom and from the area as a whole, are abstracted in Table VII as monthly averages in terms of weight in grammes per square meter area and are depicted graphically in Fig. 2. The weights given there include those of the hard parts also (wherever present), and weights excluding hard parts will be referred to in the text, in the cases where they were determined. The average for each level for each month and for the whole year has been determined by dividing the total relevant weight by the total relevant number of samples and converting it to the required scale, but as the number of samples at the different levels during a month were not always the same, the mean value for the entire region is derived by taking the mean of the mean values of the different levels.

Near the Low Water Level the weight was highest in December and it gradually declined during the subsequent months. While the table shows that the average weight in gms. per m.² decreased from 381.0 in January to 202.0 in February and rose to 251.6 in March, it is likely that there was no large decline in February and the value seen is less reliable than for the other months as it is derived from only three samples. The average value for May was 192.2 gms. but in June it suddenly fell down to 0.8 gms. coincident with the commencement of the South-West monsoon season. The low value continued till September when it rose to 7.5 gms. A slight rise recorded in July was due mainly to a single specimen of a large Nemertine worm. The September increase was due to a specimen of *Trypauchen vagina* in one of the collections. Otherwise this value would have also been very low, the next rise being only in November caused by a real increase in the bottom fauna, chiefly *Prionospio*. But even here it reaches only 9.0 gms., a value less than 1/50th of the previous December value. In the 2 fathom level, no samples were taken in December. The values from

TABLE VII.

Estimated rough wet weights of animals (including hard parts when present) per m² area, in the West Hill sea bottom during different months.

Months.		Dec. 1949	Jan. 1950	Feb. 1950	Mar. 1950	Apr. 1950	May 1950	June. 1950	July. 1950	Aug. 1950	Sept. 1950	Oct. 1950	Nov. 1950	Whole year.
Just below L.W.M.	No. of samples	4 × 3	3 × 3	1 × 3	2 × 3	2 × 3	3 × 3	3 × 3	2 × 3	5 × 3	4 × 3	5 × 3	4 × 3	38 × 3
	Wt. in gm. per m ²	491.1	381.0	202.0	251.6	217.5	192.2	0.78	2.6	0.53	7.5	0.4	9.0	128.9
2 fms.	No. of samples	..	3 × 3	3 × 3	2 × 3	2 × 3	2 × 3	4 × 3	2 × 3	5 × 3	4 × 3	5 × 3	4 × 3	36 × 3
	Wt. in gm. per m ²	..	162.7	232.0	248.3	155.0	114.2	5.8	22.3	0	Negligible	Negligible	Negligible	63.1
4 fms.	No. of samples	3 × 3	4 × 3	2 × 3	2 × 3	2 × 3	3 × 3	2 × 3	1 × 3	5 × 3	3 × 3	4 × 3	5 × 3	36 × 3
	Wt. in gm. per m ²	2.3	1.6	111.7	Negligible	0.3	1.6	0.3	0	Negligible	Negligible	0.17	0.33	6.81
6 fms.	No. of samples	..	1 × 3	3 × 3	2 × 3	2 × 3	2 × 3	3 × 3	1 × 3	5 × 3	3 × 3	4 × 3	5 × 3	31 × 3
	Wt. in gm. per m ²	..	9.6	65.2	11.0	382.3	24.5	4.0	Negligible	5.1	0.55	Negligible	0.87	35.0

8 fms.	No. of samples	..	2 × 3	2 × 3	3 × 3	2 × 3	2 × 3	2 × 3	3 × 3	4 × 3	4 × 3	4 × 3	4 × 3	32 × 3
	Wt. in gm. per m ²	..	12.7	0.5	3.7	13.8	43.5	34.5	19.1	10.8	13.6	2.5	3.3	12.5
10 fms.	No. of samples	5 × 3	2 × 3	2 × 3	2 × 3	2 × 3	2 × 3	3 × 3	3 × 3	4 × 3	4 × 3	4 × 3	4 × 3	37 × 3
	Wt. in gm. per m ²	15.8	8.5	4.0	7.5	18.3	25.8	18.2	13.8	4.6	2.8	4.5	4.3	10.0
All levels	No. of samples	12 × 3	15 × 3	13 × 3	12 × 3	14 × 3	17 × 3	12 × 3	28 × 3	22 × 3	26 × 3	26 × 3	26 × 3	210 × 3
	Wt. in gm. per m ²	169.7	96.0	102.6	87.0	131.2	67.0	10.6	9.6	3.5	4.1	1.3	3.0	44.1

January to March show a trend reverse to that seen for the Low Water Level, and gradually increases from 162.7 gms. to 248.3 gms. It, however, declines subsequently and falls down to 5.8 gms. per sq. m. in June. This value again would have been only 0.7 gm. but for the one specimen of *Trypanchen vagina*. The value shows a

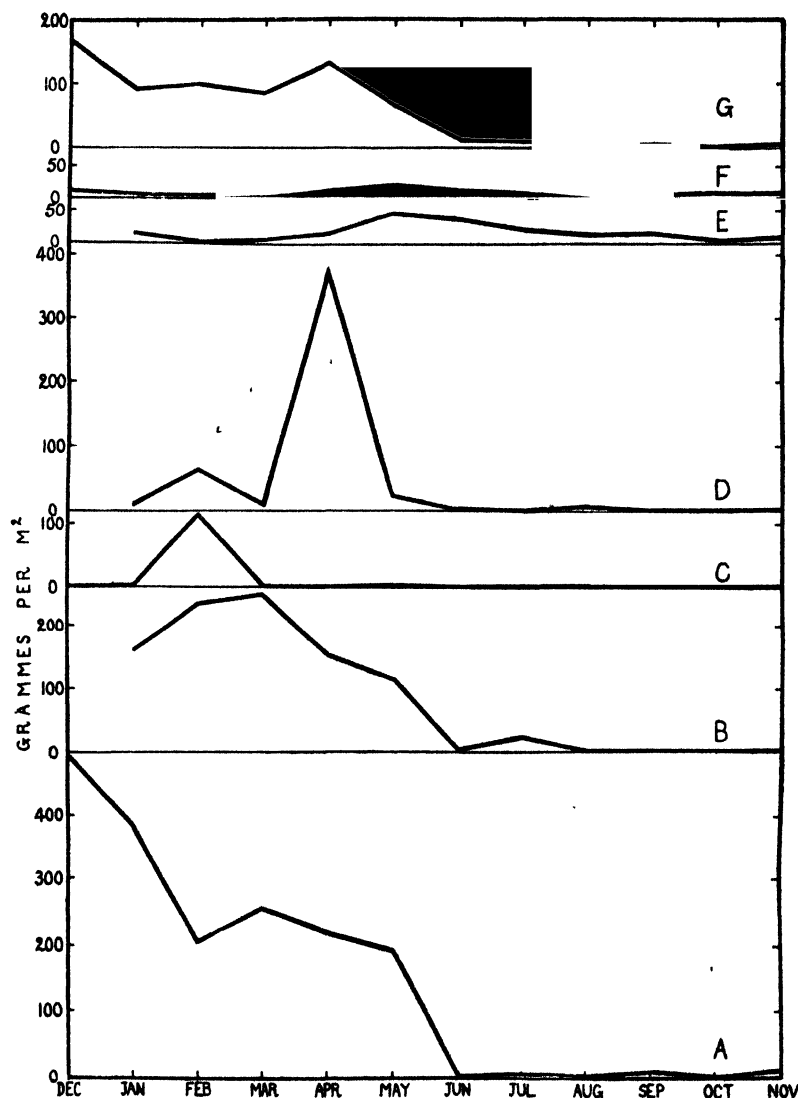


FIG. 2.—Average wet weights of animals (in gms. per m^2) at different levels of the sea bottom during the different months of the year (December, 1949 to November, 1950).

A.—Just below Low Water Mark; B.—2 Fathoms; C.—4 Fathoms; D.—6 Fathoms; E.—8 Fathoms; F.—10 Fathoms; G.—All levels together.

further rise to 22.3 in August. This was mainly due to seven unusually large specimens of the Nemertine species; otherwise the fauna was negligible and continued to be practically zero during all the subsequent months under report.

A look at the Table reveals that the 4 fathom region is completely negligible as regards animals, the average weights during the various months ranging from practically zero to 2.3 gms. per m.², except for a value of 111.7 gms. per m.² in February which was due to the occurrence of a number of *Pholas orientalis* in a single sample. If the shell weight of these bivalves were removed this average would be 26.6 gms. per m.²

The 6 fathom zone is a little better than the 4 fathom region. This level was not sampled in December, had an average of 9.6 gms. of animals per m.² in January and 11.0 gms. per m.² in March, the values for February and April being 65.2 and 382.3 gms. respectively per m.² Both these peaks in the apparent productivity of this region were due to the occurrence of *Pholas orientalis* in considerable numbers in a single sample in each of the months. If the shell weights were removed these averages would be 20.4 and 91.0 gms. respectively. In May the average value was 24.5 gms. and this was also high mainly due to a single sample with an unusual number of Ophiuroids, *Modiolus undulatus*, *Macra* sp. and Polychaetes such as *Sabellaria spinulosa*, *Pectinaria* (*Amphictene*) *Crassa*, and *Diopatra variabilis*. This was a very unusual occurrence and was perhaps the result of some currents. These forms did not appear in the subsequent samples and from June onwards the values were low, reaching nearly zero in some of the months.

There were no forms of such erratic or patchy occurrence in the 8 and 10 fathoms levels. The values for both these regions were, however, throughout rather low, though the 8 fathom region was slightly better in general and a slight rise was recorded in both regions during the months of April to May. This was due to the occurrence of *Turricula javana*, *Phyllochaetopterus* sp. and such other forms which appeared in the collections only by about April and disappeared with the commencement of the monsoon weather. The highest average wet weight of animals for the 8 and 10 fathom regions were 43.5 gms. and 25.8 gms. respectively and occurred in May. A distinctive feature of these deeper regions was that the monsoon set-back was not so severe as in the shallower regions and while a decline occurred, the lowest weights were reached only after the monsoon months. The 10 fathom level showed a higher decline than the 8 fathom level. The mean weights of animals estimated for the entire area for the different months are given in the last horizontal column (Table VII).

For the whole region, the mean value of 169.7 gms. in December fell to 96.0 gms. in January but rose to 102.57 gms. in February and again fell to 87.02 gms. in March. In April a sudden rise to 131.2 gms. per m.² was recorded. This and the February rise were due to the sudden contribution of *Pholas orientalis* from the 4 and 6 fathom levels. In June there was a sudden fall in weight to 10.6 gms. per m.² In July the value was 9.6 gms. per m.² but during the subsequent months the weight reached almost negligible figures.

From an average of all the months taken together it is possible to assess the importance of the different regions sampled with reference to production of bottom animals. The highest mean density is near the Low Water Level (128.9 gms. per m.²) and the next is at two fathoms (63.1 gms. per m.²). The 4 fathom level has the lowest value (less than 3% of the total) but the 6 fathom level gets better credit due to the occurrence of *Pholas orientalis* and gets a value of 35.0 gms. per m.² Without the shells of *Pholas*, however, this value would be only 11.9 gms. The 8 and 10 fathom levels had an average weight of 12.5 and 10.0 gms. respectively and contributed but little to the fish food of the area as most of the animals had hard skeletons, and though Nuculids (?) formed frequent articles of the diet of *Cynoglossus semifasciatus* during the monsoon months and occurred in a few thousands per m.² in some of the months the minuteness of these and the relative thickness of their shells made them rather unimportant.

The average values of the total wet weights for the four different seasons of the year for different levels of the sea bottom are shown in Fig. 3 and give a concise

and ready picture of the variations in the richness of the fauna in terms of weight during the four periods of the year which are rather distinct along this coast climatically.

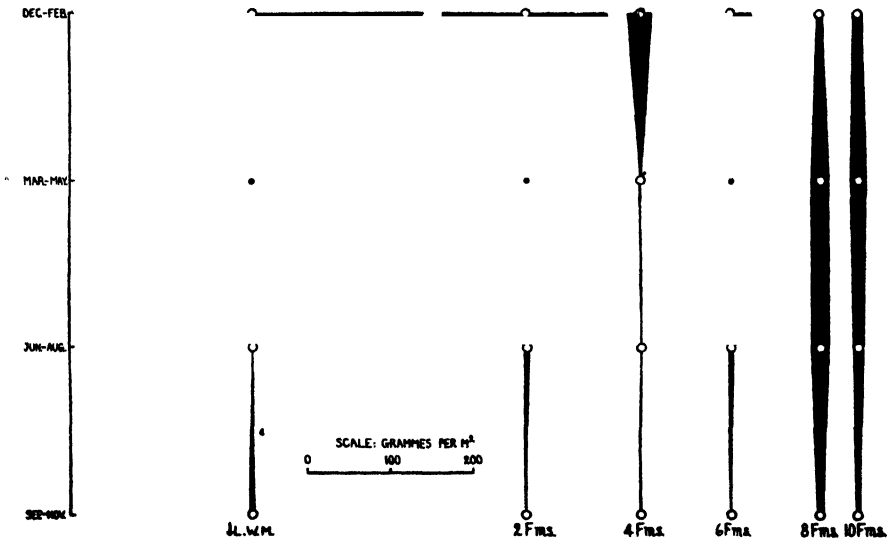


FIG. 3.—Histogram showing the seasonal averages of the wet weights of animals (in gms. per m.²) on the sea bottom at different levels.

3. *Numerical density of Prionospio pinnata.* The results of the present investigations have proved that *Prionospio pinnata* is about the most important member of the bottom infauna of the West Hill sea both from the point of view of abundance and from the point of view of value as fish food. A more detailed account of this species will, therefore, be not out of place. Table VIII shows the variations in the numerical abundance of this species as between different months of the year as well as different depths of the sea bottom. During the subsequent months there was a gradual decline in its numbers in the deeper levels and a final disappearance from the 10 and 8 fathom regions in March and April respectively. During all the months from December to May, however, the two fathom level and the region just below the Low Water Mark contribute the bulk of the species. There is gradual decline in numbers in the 2 fathom level even from the beginning while near the Low Water mark there is a slight rise from January to February and a gradual fall subsequently. This decline in numbers is perhaps the result of the cessation of recruitment of younger individuals to the population combined with removal of existing ones by the predatory activity of other animals. The disappearance of the species in June, however, cannot be considered the result of the continuation of the declining tendency already seen because of its suddenness and also of the simultaneous disappearance from the inshore area of its apparently chief predator species, *Cynoglossus semifasciatus*.

Resettlement of the species started in September but the number was only 12.5 per m.² during that month. It again occurred at all the levels, but more abundantly in the shallowest zone and though there was a gradual increase in the numbers (864.2 per m.² near the Low Water Level and 195.9 per m.² in the entire region in November) they were very inconsiderable when compared to the previous December numbers which were 4,666.7 per m.² near the Low Water Level and

TABLE VIII.

Estimated numerical distribution of Prionospio pinnata at different levels of the seabottom during the various months.

(The figures indicate numbers per m.²).

Months.	December 1949	January 1950	February 1950	March 1950	April 1950	May 1950
L.W.M. ..	4,666.7	4,011.1	5,166.7	4,555.0	4,308.3	2,477.7
2 fms. ..	..	6,983.3	5,350.0	4,470.0	2,550.0	1,806.7
4 " ..	168.9	26.7	0	1.7	0	1.1
6 " ..	..	283.3	171.1	211.1	70.0	23.3
8 " ..	..	183.3	23.3	32.3	0	0
10 " ..	532.0	75.0	41.1	0	0	0
All levels ..	1,789.2	1,927.1	1,792.0	1,545.0	1,154.7	718.1
Months.	June	July	August	September	October	November
L.W.M. ..	0	0	0	12.5	109.3	864.2
2 fms. ..	0	0	0	0	5.3	7.5
4 " ..	0	0	0	0	38.3	13.8
6 " ..	35.6	0	0	0	0	137.5
8 " ..	0	0	0	3.3	5.0	74.2
10 " ..	0	0	0	0	10.8	77.5
All levels ..	5.9	0	0	2.6	28.1	195.8

1,789.2 per m.² in the whole region. Another feature in this recolonization was that the two fathom zone showed smaller numbers than even the deeper levels.

(c) *Agitation of the sea bottom during the South-West monsoon season.* During the monsoon months of both the years 1949 and 1950 the bottom mud of the inshore sea was frequently agitated and the water was generally turbid. During the year 1949 the turbidity reached the maximum on the 24th June when the water near the shore along the entire stretch of the coast between Calicut and Pudiapa six miles north of it had turned into a thick slush of fine mud. As a result of this the rich intertidal population of *Emerita asiatica* was completely destroyed. In trying to get away from the slush, swarms of this animal migrated upwards from the usual zone and were found stranded at and above the high tide level where they formed a thick mat of dead and dying individuals. Random samples taken in a specially thick and a rather thin areas of this mat of mole-crabs showed averages of 5,407 and 513 individuals respectively *per square foot*. Other animals that were seen dead or dying and cast ashore on this day were: *Scylla serrata*, *matuta victor*, *Neptunus sanguinolentus*, *Neptunus pelagicus*, *Cavernularia* sp. and species of hermit-crabs. Two days later when the area was examined again, the slush had disappeared completely though the water remained slightly turbid. Detailed examination of the area during subsequent days revealed the total absence of both *Emerita* and *Donax* along the entire stretch of the shore between Calicut and Pudiapa. As already mentioned, it was not until October-November, 1950, that the region was colonized again by these two species. A similar but in some respects unprecedented phenomenon occurred during July, 1950. This consisted in the

emergence of a wide mud flat near the shore extending above the general water level, and spreading out for four to five miles along the shore. This appeared on the 5th July, following a few days of rough weather when an agitation of the sea bottom in the 2 and 4 fathom regions was reported as occurring due to an under-current ('Adiyilakam').

The flat thus formed seems to have remained in that condition for several days but had diminished in extent by about the 18th of July the seaward extent then being only about half a furlong. During the subsequent days there was a gradual dissolution of the flat from both the north and the south and it had finally completely disappeared by the morning of 23rd July.

Examination of the material of the mud flat mentioned above showed that it had a fine, soft, slimy consistency and resembled in this as well as in its greenish brown colour the mud of the inshore area of the previous weeks. The particles were very fine and almost all passed through a 100 mesh sieve. The animal contents of the mud were *Trypauchen vagina*, *Sternaspis scutata*, *Lumbriconereis latreilli*, a Syllid species and a nemertine species all of which were characteristic of the inshore fauna. Large numbers of shells of *Pholas orientalis* were present and a high frequency of *Trypauchen vagina* which had appeared in the marine inshore area with the onset of the monsoon conditions, was characteristic of the mudflat. It seems obvious that the whole phenomenon was the result of a shoaling up of a large quantity of mud from the inshore area due to some mechanical disturbance. During the subsequent period most of the area inward of the 8 fathom depth was characterized by 'liquid mud' at the bottom, the mud particles of the flat mentioned above having spread out in the area and remaining unconsolidated for a long time. From about the middle of September the 'liquid mud' was less frequently noticed but whenever there were strong tidal currents there was a disturbance of the fine mud and the grab brought up only slush and no clumpy mud of the usual consistency.

During the mudflat formation mentioned above no large scale mortality of animals of the type seen on 24th June, 1949, was noticed although some fish and crabs were trapped and suffocated to death. But if a population of *Emerita asiatica* were present before the phenomenon, as during the period before the slush formation of the previous year, there might perhaps have been a similar mortality of the species. But apart from the trapping or choking effect in the case of animals engulfed in the mudflat, the formation of the latter was not apparently accompanied by any release of substances deleterious to animal life in the neighbourhood and it was in fact noticed that, when the last remains of the mudflat finally dissolved away at West Hill, it was immediately followed by considerable fishing activity and a good miscellaneous catch of prawns, crabs, rays, soles and other fish was available just about 50 yards from the shore in the identical area.

6. DISCUSSION.

(a) *Features of the fauna.* From the results summarized above it is possible to make out certain marked features in the bottom fauna of the area investigated. The most important of these is that the animals are not uniformly distributed at all the depths even within the limited inshore fishing area, there being a zonation in vertical distribution both qualitatively and quantitatively although the nature of the bottom is practically the same. The reasons for the existence of such zonation must be sought in the differences in the complex of environmental conditions such as salinity, temperature and pH ranges, the incidence of light, the incidence of currents and turbulence effects on the bottom, between the deeper and the shallower zones. The deeper region has a more stable environment in that the range of variation of these factors is more limited there than in the shallower regions. In Table II are given the salinity values of the shore water (which may be con-

sidered as having roughly the same salinity as the bottom water up to a few fathoms) and the 8 fathom bottom water during the months of August to November. There is considerable difference between the two sets of values. That the 8 and 10 fathom levels are not probably affected by turbulence effects is seen by the fact that during the mudflat formation in July, 1950, these two levels were undisturbed while the mud from the 4 fathom zone and inwards was disturbed and transported shoreward. That there was no material derived from the deeper levels in the mudflat material was evidenced by the fact that there was no trace of the Nuculids (?) or their shell pieces and the Maldanid worms or their tubes, in the material left on the sieve after washing the sample. These should have occurred if the material had been derived from the deeper level. Moreover the fact that the 8 and 10 fathom levels did not suffer a disappearance of their fauna shows that there was no large mechanical or other disturbance at the bottom there. The 4 fathom region has revealed itself in these studies as the boundary between the shallower and deeper zones but why the species and numbers must be so few there is not clear, though an indication is obtained by the fact that on some occasions 'liquid mud' was reported from this level even during the earlier months of these investigations. But for some adverse factor we should have expected the number of species to increase in the transitional zone, some of the members of the zones on either side of it persisting. The occurrence of 'liquid mud' indicates a loose bottom which is a bad substratum.

The second important feature of the fauna is that its seasonal behaviour is different in the two different zones mentioned above. The animals in the shallower region are almost all likely to disappear in every South-West monsoon season. Such disappearance has been noticed in two successive monsoon seasons and a successful recolonization of the region has been noticed in 1949, while in 1950 although a recolonization commenced, certain other factors inhibited its success. Fig. 4 shows the curves of the surface and bottom salinity in the 8 fathom region and those of the total wet weights of animals for the 2 fathom and near low water mark levels taken together and the 8 and 10 fathoms taken together. The value of the surface salinity of the 8 fathom region may be expected to be nearer to the shallow zone bottom salinity than would be the 8 fathom bottom salinity. A rough correlation can be seen from these curves between a *steep drop* in the surface salinity and the disappearance of the shallow level fauna on the one hand and between the *slight* change in the bottom salinity and the non-disappearance of the deep level fauna on the other. Although there was already a tendency towards a decline in density before the monsoon period began, the disappearance was sudden after the commencement of the monsoon and the main factors responsible for this can probably be fixed as the drop in salinity (and the pH and temperature) consequent on the coming in of fresh-water floods into the sea. The suddenness of the disappearance of the fauna appears to rule out any argument that the disappearance may be the result of continued action of some predator species, as already mentioned.

The third important feature is that the main bulk of the fauna for the entire region is contributed from the region between the Low Water Mark and a little beyond two fathoms. The animals from this region consisted mostly of polychaetes and were dominated by *Prionospio pinnata*. As animals with hard parts were only occasional and even then small and negligible in proportion, the total of the wet weights given for these two levels would be very near the total wet weight of the fish food of the inshore region, some extra quantities being, however, available from *Pholas orientalis* of the 4 and 6 fathom regions. The 8 and 10 fathom levels contribute very little directly to the fish food on account of the shelled animals. As in the near shore regions all the animals are destroyed and a new generation is developed each year, the 'stock of the moment' if estimated at any given time will be equivalent to the total annual production minus the possible increase due to

growth and recruitment during the remaining part of the year and the loss due to predators and other causes.

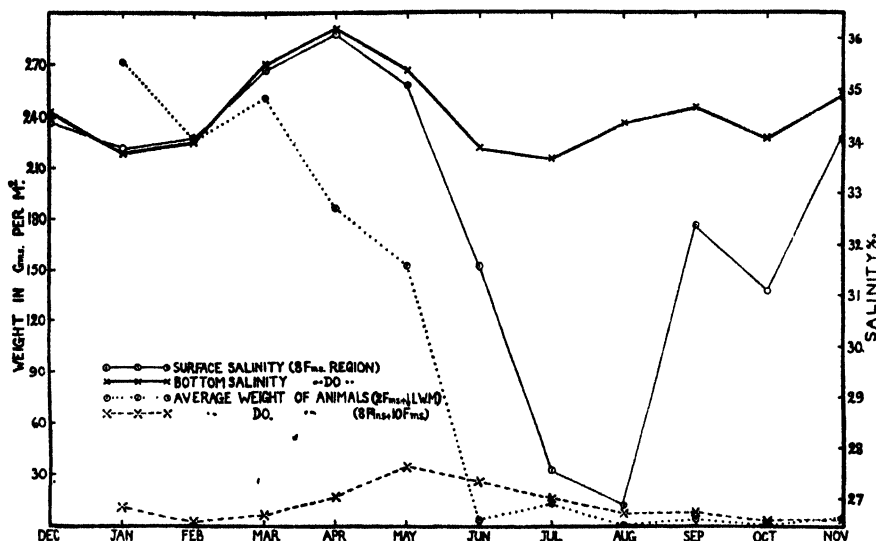


FIG. 4.—Correlation between the density of the bottom fauna and the salinity of the sea water (see text).

(b) *Failure of recolonization of the shallow area after the monsoon season of 1950.*

While during the year 1949 an establishment of the post monsoon conditions and a rising salinity were accompanied by a rapid settlement and development of the organisms in the shallow area, during the year 1950, there was a long delay in recolonization and as there were no considerable numbers of either species or individuals even at the end of November, this may be interpreted as a failure also. An examination of the available data points to the occurrence of 'liquid mud' in the sea bottom for several weeks after the monsoon ended, as an important difference between the previous year and this one and as all the other conditions seem to be satisfied, namely the presence of suitable temperature and salinity conditions judging from the conditions prevailing during the corresponding season of the previous year, and the presence of settling larval forms in the relevant months, it has to be concluded that the nature of the bottom material must have been responsible for the failure of the recolonization. Thus it appears that the nature of the bottom material is the most important in determining the behaviour of the fauna in this region. That the substratum is one of the important factors influencing the general ecology of any aquatic fauna is fairly well known (e.g. see Pearse, 1939; Jones, 1950; Hora, 1936 and Hora and Nair, 1943). The importance of the nature of the substratum in the metamorphosis and settlement of several species of bottom invertebrates has been brought out by the work of Mortensen (see Thorson, 1946), Thorson (1946), and particularly Wilson (1937 and 1948) and Day and Wilson (1934) who worked on polychaetes. Further work on the influence of the bottom material on the bottom fauna of the Malabar coast would be of considerable interest and value.

A mud bank has long been known to be present at Calicut and to be shifting now and then between West Hill and Calicut. The last time it was seen was in 1937 'when the north pier at which there is generally fifteen feet or so of water at its outer end suddenly appeared high and dry above a mud bank' (Bristow, 1938).

It was then said that it extended 'also from the north pier to Elathur Cape' (see Fig. 1). No information is available about its subsequent movements. It seems obvious that the mudflat that appeared in July, 1950, was a manifestation of one of the movements of the Calicut mud bank, and it now seems to have settled down near West Hill as can be judged by the fact that the sea was calmest here during the months following mudflat dissolution, even when the weather was bad and the neighbouring areas of the sea were rough. There have been many theories in the past about the origin and movement of these mud banks (Bristow, 1938). Du Cane, Bristow, Brown and Keen (1938) after examining the problem in some detail have stated as follows, regarding the mode of formation of these banks: 'the banks are formed in two ways, acting separately or together, viz.—(a) by the depositing of material directly derived from detritus brought down by the rivers, (b) by the throwing up and redepositing of areas of similar mud from the sea bed during rough seas'. The present observations on the mud bank formed at West Hill go to prove that the material of the bank was derived from the inshore sea bottom mud itself and to this extent support the opinion advanced by the authors mentioned above.

(c) *Applicability of the general results of this work to the Malabar Coast as a whole.* In the climatic and other features, West Hill seems to be typical of coastal Malabar. The same is true of the sea bottom except for the fact that the mud bank has now extended into the area of investigations. While it is not possible without examining some more regions, to make any generalization about the productivity of bottom fauna in the inshore waters along the Malabar Coast as a whole, it seems justifiable to expect the fauna to have the same general features in the other regions of the coast also, the formation of the fauna being regular and cyclical wherever there is a relatively stable mud at the bottom but showing considerable fluctuations wherever there are mud banks. These exist at several other places along the coast and the effect of the Calicut mud bank on the fauna, when more fully known, will help in assessing the influence of the mud banks along the coast in general on the production of the bottom fauna and also on the inshore fisheries.

7. SUMMARY.

1. Qualitative and quantitative studies have been made, of weekly or fortnightly samples taken with the Peterson Grab at different depths of the inshore sea bottom during the year December, 1949 to November, 1950, and along with these are considered the results of some qualitative samples examined during the months July to November, 1949.

2. The general features of the Malabar coast and the physical and hydrographical features of the area selected for intensive studies are described. A special feature of the Malabar coast is the occurrence of peculiar *mud banks* at various places along the coast. A great agitation of the sea bottom was noticed in the south-west monsoon season during 1949 and 1950.

3. There was a vertical zonation in the distribution of the fauna in the inshore fishing grounds. The 10, 8 and 6 fathom levels formed one zone while the 2 fathom and the near low water levels formed another zone, the intervening 4 fathom region being very poor in fauna.

4. The zone in the shallow region was rich in fauna during the premonsoon months and was dominated by polychaetes and phoronids. During the monsoon months this rich belt disappeared altogether while the fauna of the deeper levels also declined.

5. Recolonization of the shallow region started when the postmonsoon conditions were fully established but was very slow and the density of the fauna was very low even by the end of November. Among the factors determining the behaviour of the fauna, the nature of the bottom material is probably the most important.

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9. APPENDIX.

SYSTEMATIC LIST OF THE SPECIES CITED.

1. ANNELIDA

Polychaeta

Sternaspis scutata Ranzani
Diopatra variabilis Southern
Prionospio pinnata Ehlers
Lumbriconereis latreilli Audouin and Milne Edwards
Glycera alba Rathke
Pectinaria (Amphictene) Crassa Grube.
Sabellaria spinulosa Leuckart

2. MOLLUSCA

Lamellibranchiata

Lucina vesicula (Gould)
Theora opalina (Hinds)
Donax cuneatus Linnaeus
Pholas orientalis Gmelin
Modiolus undulatus (Dunker).
Meretrix casta Deshayes
Arca (Scapharca) gubernaculum Reeve
Siliqua radiata (Linnaeus)

Gastropoda

Turricula javana (Linnaeus)
Acteocina Townsendi (Melvill)
Duplicaria duplicata (Linnaeus)

3. ARTHROPODA

Crustacea

Cheiriphotis megacheles (Giles)
Metapenaeus affinis (Milne-Edwards)
Alpheus malabaricus Fabricius
Emerita asiatica (Milne-Edwards)
Matuta victor Fabricius
Neptunus pelagicus (Linnaeus)
Neptunus sanguinolentus (Herbst)
Scylla serrata (Forsk.)

4. PISCES

Trypauchen vagina (Bl. Schn.)
Solea ovata Rich.
Cynoglossus semifasciatus Day.

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STRUCTURAL PETROLOGY OF SOME QUARTZITES OF PALNAD

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(Communicated by Prof. C. Mahadevan, F.N.I.)

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INTRODUCTION.

Structural petrology or 'petrofabrics' which deals with the study of rock fabric is a science which has developed during the last three decades. It comprises a study of all the spatial data, macroscopic and microscopic, which go to form a complete vector-picture so far as this is legible in the make-up of the rock. Thus, it is an integration of the mutual relationships of various kinds of crystalline aggregate within the rock, of the crystals of constituent minerals within such aggregates and even of the ionic groups and individual ions that make up the space-lattice of each component crystal. Investigations on rock fabric in minute detail may be said to have been begun by Sander (1930) and Schmidt (1932). They have systematized the new method of the study of rock structures by statistical determination of the pattern of orientation of crystallographic or other optical elements of the constituent minerals and have thus laid down the principles for kinematic and dynamic interpretation of the fabric. This method has later been taken up in the United States of America and pursued to a great extent. The treatises of Knopf and Ingerson (1938) and Fairbairn (1949) are very comprehensive in this respect as they deal with the field and laboratory technique. In India, this line of research was not introduced till a few years back. The only published work seems to be that of Sen (1948, 1949) which gives an account of the mineral orientation in the Manbhumi granite.

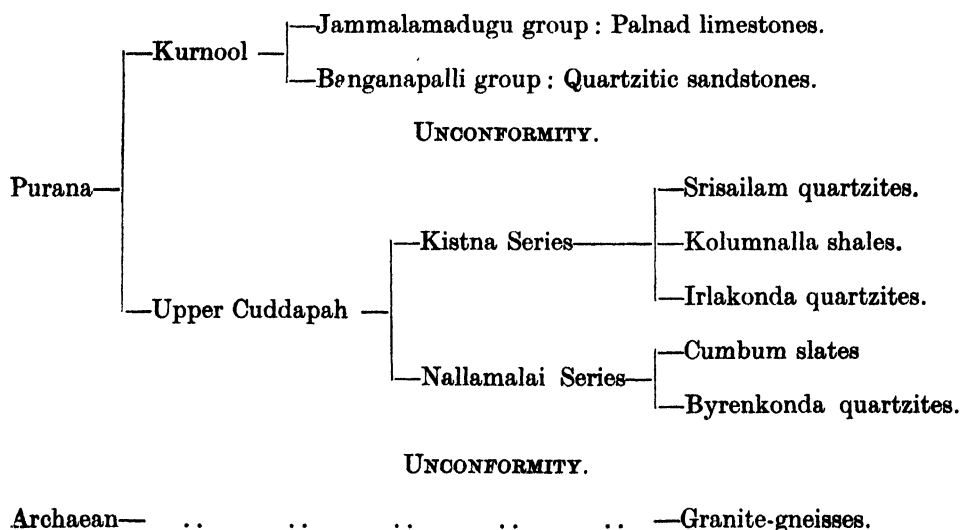
It is very well known that the various members of the Archaean and Purana formations are deformed and in some cases there is great doubt as to their positions in the stratigraphic succession. In this respect, the Cuddapah and Kurnool formations with quartzites in various horizons afford an interesting study. In particular, in the Palnad taluk the geology of which has been studied by the author (1953), limestones, quartzites and shales, which King (1872) describes as Palnad beds, are so peculiarly associated that the quartzites seem to both overlie and underlie the limestones. The author has shown that quartzites of different stages of the Cuddapah system are involved and that they have been further faulted into their present positions. With a view to find out the amount of deformation and

therefrom the source and direction of the movements that caused the deformation of the various quartzites this study of their fabric is undertaken. It is also intended to ascertain on the basis of the type and amount of deformation the possibility of their correlation with the various members in the standard Cuddapah and Kurnool succession.

The material on which this work is based was obtained from an area in Guntur District included in the Survey of India topographic sheet Nos. 56-P/11 and 15.

GENERAL GEOLOGIC DESCRIPTION OF THE REGION.

The formations in the area comprise essentially the Upper Cuddapah quartzites which occur interbanded with siliceous shales and limestones and lie unconformably over the Archaean granite-gneisses. Banganapalli quartzitic sandstones and Palnad limestones also occur especially in the northern part of the area. The geological succession is as follows:



The quartzites usually form the hill masses and are well exposed. Here, along the eastern margin of the Cuddapah-Kurnool basin, they are only a few hundred feet thick. They have a general N.E.-S.W. strike and are mostly folded. The amount of dip varies, being commonly high around 50° and 60° tending here and there to verticality. Quartzites of Nallamalai series occurring in Galimottu Konda are overlain by quartzites of the Kistna series disconformably, variation in the amount of dip between the rocks of the two series only being significant. In the Kistna series various bands of quartzites occur intercalated with shales. They have been divided into two groups the lower one being called Irlakonda quartzites and the upper Srisailam quartzites as developed in the type area of Srisailam along the Kistna valley. It has not always been possible to assign some bands to one or the other of the two main horizons in the series. A striking example of the overturning of folded Kistna quartzite beds near Karempudi has been recorded by Mahadevan and Umamaheswararao (1951). Further, faulting has seriously affected the relative positions of the Cuddapah and Kurnool formations in the region. The geological structure of the area is thus intricate, the various members exhibiting very well the effects of deformation due to faulting and folding movements and also of possible recrystallization.

TEXT-FIGS. 1-8.—Petrofabric Diagrams of Some Quartzites of Palnad
(All measurements of quartz refer to the pole of the optic axis.)

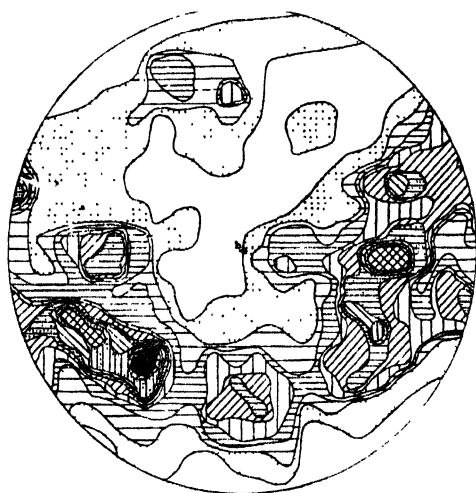


FIG. 1.

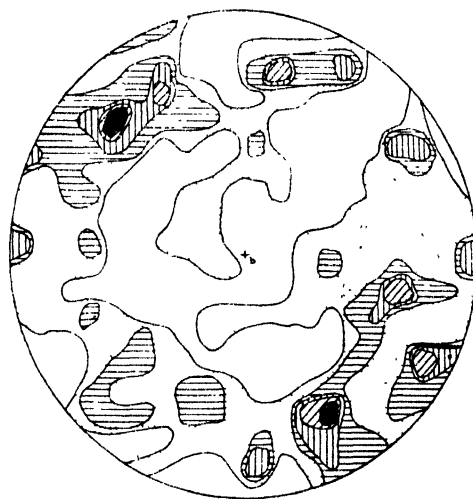


FIG. 2.

FIG. 1. Nullamalai (Byrenkonda) Quartzite (P11) from Sejara Konda ($\cdot 1133$).

210 quartz grains; 5.4-5.4-3.5-3.2-5.2-1.5-1.0-5%.

FIG. 2. Quartzite (P15) constituting the top band of the Nullamalai series, locally developed in Pasam Konda ($\cdot 1386$).

200 quartz grains; 5.4-3.2-1%.



FIG. 3.

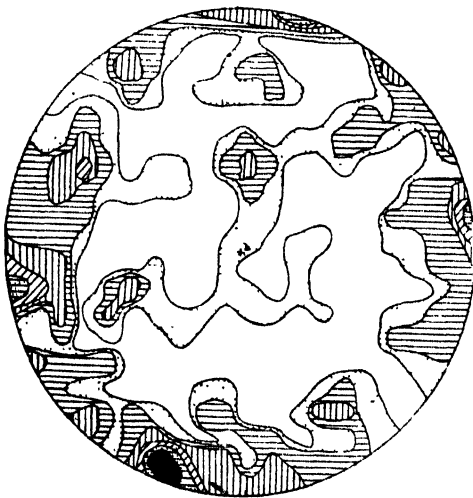


FIG. 4.

FIG. 3. Kistna (? Srisailam) quartzite (NK 30) from Gurralla Gattu ($\cdot 633$).

260 quartz grains; 5.4-5.4-3.5-3.2-5.2-1.5-1.0-5%.

FIG. 4. Irlakonda quartzite (9) from the band intercalated in the Lower Kistna series of rocks in the lower levels of the hill mass about 3 miles S.S.W. of Adigoppula.

200 quartz grains; 6.5-4.3-2.1%.



FIG. 5.

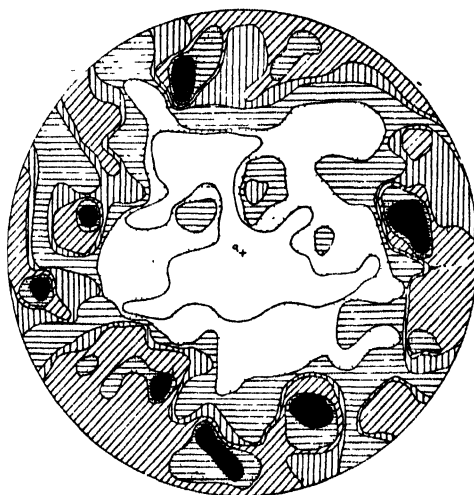


FIG. 6.

FIG. 5. Kistna (Srisailam) quartzite (K14) from the hill $1\frac{1}{4}$ miles S.W. of Karempudi.
200 quartz grains; 5.4-3.2-1%.

FIG. 6. Quartzitic sandstone homotaxial with the Banganapalli sandstone from the hill $\frac{3}{4}$ mile N.W. of Durgi.
300 quartz grains; 3.2-5.2-1.5-1.0-5%.

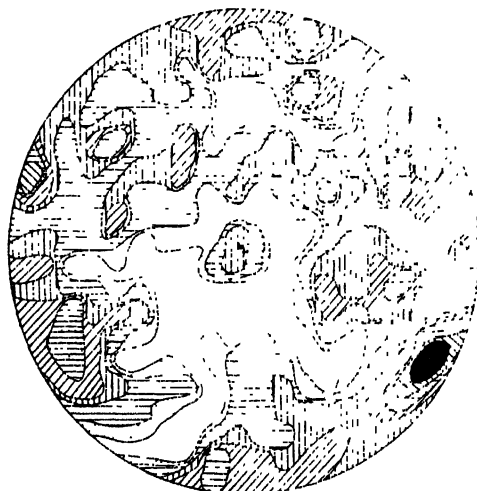


FIG. 7.

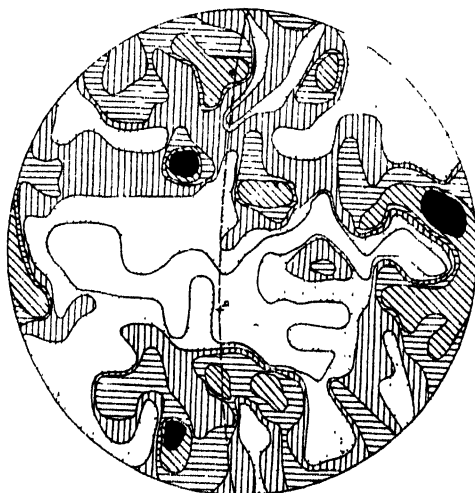


FIG. 8.

FIG. 7. Quartzitic sandstone (24) homotaxial with the Banganapalli sandstone, from Manchikallu.
325 quartz grains; 3.5-3.2-5.2-1.5-1.0-5%.

FIG. 8. Quartzitic sandstone (41) homotaxial with the Banganapalli sandstone, from the hillock S.W. of Atmakuru; ab - megascopic foliation.
150 quartz grains; 3.2-5.2-1.5-1.0-5%.

FABRIC OF THE QUARTZITES.

(a) *Petrography*.—The quartzites are very compact and well-jointed. Two sets of jointing, each perpendicular to the other, are conspicuous. They trend E.N.E.-W.S.W. and N.N.W.-S.S.E. The quartzites are generally impregnated with vein quartz which commonly runs in north-south direction. Under the microscope in the crossed nicols position, they exhibit a typical mosaic structure. There is variation in the size of the quartz grains. The inter-spaces of the bigger grains are filled up with silica in the form of quartz. The bigger grains are irregular in form and generally exhibit undulose extinction. All the grains have undergone much compaction and granulation. The quartzites are, in general, waxy-looking and white to reddish brown in colour, though in places they are dark-coloured. Of the Kistna quartzites, the Srisailam quartzites are relatively coarse-grained.

(b) *Macrostructures and Microstructures*:

Macrostructures.—The structures of the quartzites which are clearly discernible megascopically either in hand specimens or in their natural setting in the field are here referred to as macrostructures. Of them, a single foliation, probably the axial-plane foliation, is the most important. It is pronounced in most of the rocks, especially in the ferruginous varieties. The orientation of this foliation is about N. 75° E. around Karempudi, tending to be about N. 60° E. in the eastern parts of the area. Shear joints are common. They are mainly in two sets. They appear to pass into the plane of foliation. Lineation is also clearly visible in the hand specimens. It is here commonly found out by the intersection of axial-plane foliation and bedding. A feature common to most of these rocks is the veining by quartz. Thus, there is ample evidence to show that the quartzites megascopically exhibit deformation.

Microstructures.—The deformation of the quartzites is further evidenced by their microstructures as observed in individual quartz grains. The important microstructures include Deformation or Bohm lamellae in quite a number of the quartz grains, secondary quartz enlargement of the original grains, undulatory extinction in the mineral and also sutured boundaries between the grains. The Deformation or Bohm lamellae are very common in quartz, mostly occurring in the central portions of the grains. According to Ingerson and Tuttle (1945), they can be (1) planes of liquid inclusions, (2) healed fractures, and (3) translation glide planes. Fairbairn (loc. cit.) interprets the lamellae as translation glide planes, containing the glide line ($m:r$). The relation between the Deformation lamellae and the fabric of the deformed rock is indicated by Ingerson and Tuttle (1945). According to them, the angle between the optic axis and the pole of the Deformation lamellae varies with the angular distance from the optic axis of the grain to the *B* fabric axis. That secondary enlargement of the original quartz grains has occurred in many cases is proved by the incising of a thin film of impurities at the original grain surfaces. Undulatory extinction is very commonly observed in the quartz grains. The magnitude of this change in optic orientation varies very much from grain to grain within the same sample and in different samples. The boundaries between some grains are sutured and there seems to be interpenetration of grains. Further, the big quartz grains are broken and along their boundaries are disposed small fragments of quartz which may be the result of recrystallization. In addition, the distortion in the shapes of the grains in some cases has been so much as to ultimately give rise to very elongate, nearly cylindrical shaped quartz grains. The dimensional elongation is always in a direction either very nearly parallel or perpendicular to the optic axis direction of the mineral.

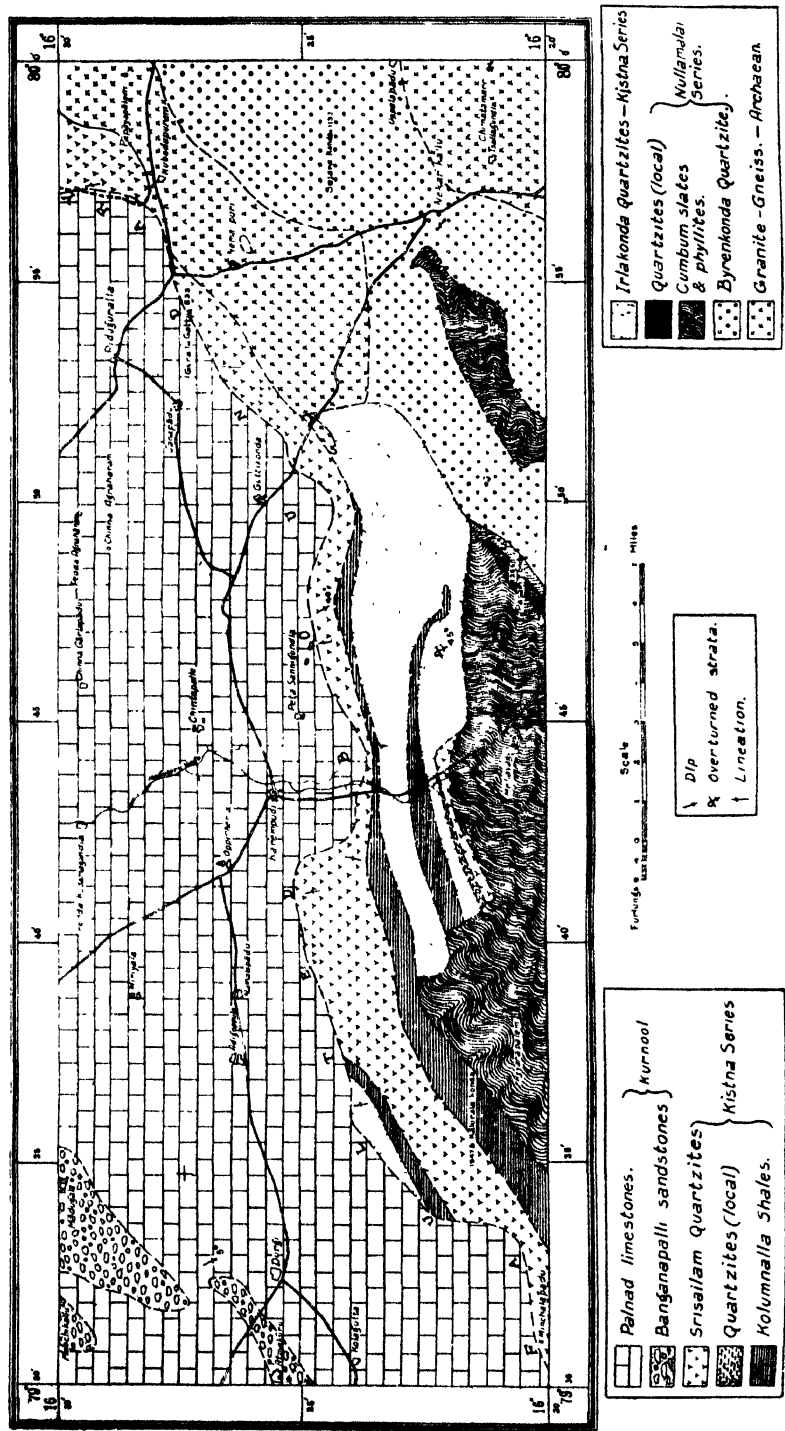
Of the intergranular structures seen under the microscope, microveins of quartz are the most important. They occur as definite bands in the big quartz grains. They thus form planar structures. Another common structure, which probably represents the original sedimentary nature of the rocks, is the presence of thin

laminae or streaks or lines of heavy mineral concentrates, particularly of hematite and magnetite.

(c) *Methods of study*.—A number of specimens of quartzite collected in the field were oriented with reference to their macrostructures and the geographic distribution. Eight of the specimens from different parts of the area but representative of the major stratigraphic horizons—Nallamalai and Kistna of Upper Cuddapah formation and Banganapalli of Kurnools—were selected for detailed study. The fabric axes were located in each case with the help of structures such as foliation and with the knowledge of the fundamental principles of structural petrology. Megascopic foliation surfaces in all examples are here designated as *S*-surfaces. The specimens were then cut in such a way that the resulting cut bits are normal to the *b* fabric axis, which again is deduced from the linear schistosity (lineation) of the rock. Only quartz, the chief and in some cases the only constituent of the quartzites, has been studied. The 4-axis Universal Stage was used during these investigations. The number of measurements made in each slide varied and was mostly from 150 to 350. The diagrams were all plotted on a Schmidt 20 cm. equal-area lower hemisphere projection, and were all counted with a one per cent circle.

(d) *Results of Fabric Studies*.—Preferred orientation of grains according to space-lattice structure is expressed in orientation diagrams by the presence of localized areas, called maxima, and arcuate zones, named as girdles, within which the poles of the measured optic axes are densely concentrated. Accordingly, the most striking feature of the quartz diagrams of the quartzites is a constant tendency for the plotted poles of quartz axes to lie on a more or less well-marked girdle—the girdle parallel to the *a c* plane. The quartzites are undoubtedly *B*-tectonites, including the sandstone-like facies corresponding to the Banganapalli stage of the Kurnool formation, though in the latter case, the girdle is not particularly well-defined. The *a c* girdles are a common type of deformation fabric and have been recognized and described by Schmidt (*ibid.*). Their development, according to him, is due to several processes in the course of deformation. In the initial stages, each grain tends to rotate by movement at intergranular surfaces. By rotation one of the glide planes and associated glide directions in the crystal is brought into coincidence with the plane and direction of shear imposed on the rock and thus the rotation of the crystal ceases, though it begins to yield by gliding, ultimately giving rise to a tectonite. In quartz the shear plane directions may be rhombohedra, prism or basal planes. Further, it is believed that *a c* girdles develop as a result of translatory and rotary forward movement in the tectonite perpendicular to the lineation *b*.

In general, the quartz maxima in these diagrams are peripheral lying on or near the periphery of the *a c* girdle. This is particularly seen in figures 3, 4, 5 and 8, and also to some extent in figure 7. The greatest concentrations of optic axes are usually in two directions nearly perpendicular to *b*, but inclined generally at 40° to 50° to the geographic horizontal, though in figure 4, one set of maxima is disposed at about 80° from the horizontal. In figures 2 and 6 are also seen the girdles, but the maxima which are of fairly great concentration are not peripheral, but lie on an annular area bounded by small circles of the projection sphere drawn at 50° to 55° and 72° to 75° from *b*. This cleft girdle pattern in which the *a c* great circle is a band of low concentration flanked on either side by high concentrations of quartz axes along small circles has been noted by Fairbairn (1939) in the fabrics of quartzites of Brome County, Quebec, and has been also recorded from other regions. Figure 1 which is the orientation diagram of a quartzite of Nallamalai series exhibits a distinct two-girdle pattern. This is in all probability due to partial over-printing of one *B*-tectonite fabric upon another during the course of two independent deformations governed by unrelated systems of stress. The angle of intersection of girdles in this case is nearly 90°, and hence the rock is a $B \perp B'$ tectonite. Though



TEXT-FIG. 9.—Geological and Structural Map of the Palnad Area.

the pattern of two crossed girdles could be the product either of one continuous deformation or of two distinct but closely related phases of a single deformation, here it could be taken as indicating two independent deformations, one at the end of the Cuddapah period and the other after the close of the Kurnool period. In this connection, it is interesting to note that Riley (1947) has recorded pronounced deformation in quartzites belonging to the Algonkian system which is homotaxial with the Purana system of Indian geology.

DISCUSSION OF THE RESULTS.

From the foregoing account, it is clear that the quartzites in the southern and eastern parts of Palnad Taluk, belonging to both the Upper Cuddapah and Kurnool systems, were brought to their present state of regional metamorphism by at least one and possibly two independent deformations. The movements associated with the more important and last deformation must have acted in a plane tending roughly E.N.E.-W.S.W. or N.E.-S.W. This is clearly evidenced by the general foliation strike of the rocks, which is E.N.E.-W.S.W. over a major part of the area around Karempudi, which swings to nearly N.E.-S.W. in the Janapadu and Konanki localities. The fold axes in the region seem to follow very closely the direction of tectonic transport. This feature is to be viewed in conjunction with the thrust faulting which has been brought to light by the studies of the author (*ibid.*) on the adjoining area to the north of the present one and which continues into this area as well. Even around Karempudi, where overfolding of the quartzites and shales of the Kistna series has been recorded, there is evidence of rupture of the rocks and of their constituting a mass thrust over the younger Palnad limestones. Thus, in this area, which constitutes the eastern margin of the Cuddapah-Kurnool basin and which is in a thrust zone, the transport parallel to fold axes is not a surprising feature. In fact, such parallelism is found in most thrust zones that have been studied and is well known. Further, there is proof of the quartz grains in these rocks markedly elongated in a direction more or less at right angles to the direction of transport. In other words, the lineation is N.N.W.-S.S.E. to N.W.-S.E.

The three specimens of Banganapalli quartzitic sandstone studied exhibit preferred orientation, though not to the same extent as the others. The maxima are not of relatively great concentration. This is probably to be attributed to the effects of only one deformation at the close of the Kurnool period, which was not probably of the same intensity as the one that occurred earlier. This is in conformity with the field observations that the Kurnools are much less metamorphosed than the Cuddapahs. The concentrations in figures 2 and 6 fall on or in between the circles which include maxima IV and VI of the synoptic diagram of Fairbairn (*ibid.*). This feature is significant and it is in accordance with the general findings on the distribution of sub-maxima in tectonites in connection with the proving of the hypothesis postulated by Griggs and Bell (1938) of fracture of quartz during deformation.

SUMMARY AND CONCLUSIONS.

The quartzites of Palnad are shown to be B-tectonites. The direction of predominating movement (tectonic transport) seems to be in the plane running N.N.E.-S.S.W. to N.E.-S.W. The lineation which is N.N.W.-S.S.E. is well marked. Evidence is presented in favour of two independent deformations in some of the quartzites. The Banganapalli quartzitic sandstones which exhibit a relatively lesser amount of preferred orientation of their grains and which are relatively less deformed are probably the result of only one deformation.

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X-RAY STUDY OF COLLOIDAL COLOURED GLASSES

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(Communicated by Prof. K. Banerjee, F.N.I.)

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GENERAL INTRODUCTION.

Many investigations have been carried out on the coloration in glass and Weyl (1945) has contributed much towards the understanding of that subject. In dealing with the problem of coloured glass, it is necessary to take into account the structural as well as chemical considerations of the glass base and experimental conditions. The problem may be divided into two sections: (a) the colouring element is a metallic atom, and (b) the colouring element is metallic ion.

The study of glass systems with particular reference to the structure of glass is engaging the attention of a number of physicists and chemists. Generally the oxides most suited for the formation of glass are those of the elements which provide small and highly charged ions like B^{+3} ($r = 0.20$ Å), Si^{+4} ($r = 0.41$ Å), P^{+5} ($r = 0.34$ Å), etc. The classical work on the glass-forming ability of oxides with particular reference to the structure has been done by Goldschmidt (1926). Later on Zachariasen (*J. Am. Chem. Soc.*, 54, 3841, 1932) published an interesting paper on the structure of glass wherein he predicted a random network type of structure extended in three dimensions. From that point of view, it will be interesting to study the distribution and the state of existence of the noble metal salts in the glassy matrix.

Colloidal particle and its stability in different media.—The stability of the colloidal particle is determined to a great extent by the nature of the dispersion medium. Svedberg (1907) showed that the Colloidal solutions of noble metal in ethyl ether is the least stable while the solution in water is the most stable. In the case of solid dispersoid both disperse phase and the dispersion medium are solid, but both of them need not be crystalline. All the glass systems for the present investigation consist of the dispersion of a crystalline substance in the amorphous medium.

In the preparation of colloidal coloured glass, sometimes it is necessary to add SnO , PbO or ZnO to develop the colour of ruby glass as well as to stabilize the colloidal solution. It is well known that the presence of a small amount of the above oxide in the melt increases the solubility of the noble metal as well as determines the particle size of the metal. Numerous parallel examples are known in liquid systems where the presence of a small amount of a third substance increases the solubility of a substance in another substance to a considerable extent. The classical example is the addition of sodium salt of benzol sulphonic acid in benzoic acid-water system.

PRESENT WORK.

The nature of colloidal particles of Au, and Pt, in glass systems and their influence on the structure of glass have been investigated. Zsigmondy (1909) first demonstrated the existence of colloidal gold in Ruby glass by the Ultramicroscope. Further it is known that elemental carbon, sulphur, selenium, solid solution

like CdS and CdSe, etc., can exist in the glassy matrix. It is also known that in a glass phase, the existence of colloidal and crystalline phase has been found to be possible.

There is a controversy regarding the mechanism of the growth of ruby colour in glass. One school of scientists believes that Au dissolves as Au^+ or Au^{+3} ions in molten glass and that the formation of ruby colour on low temperature heat treatment results from reduction of the ions to metallic gold by reducing agent present in glass. The other school believes that Au dissolves initially as colourless atoms, and glass forms a supersaturated solution of metallic Au on cooling but at the same time containing larger gold particles as nuclei and finally reheating causes growth of these nuclei to produce colour. On the basis of above observations, it would be fruitful to extend the investigation to study the course of formation and the state of existence of Au and Pt, in different glass bases. Practically a very small amount of work has been done on the above problem. Because the complete investigation of glass at the ordinary temperature is limited by the rigidity of the dispersion medium whereby electrokinetic phenomena, etc. cannot be studied. However, we have studied the following different aspects of the problem and for the present, the investigation is confined to Boric oxide glass base containing different network modifying cations.

1. Vitreous limit of each type of glass composition.
2. Colour of the glass specimen.
3. X-ray analysis of glass samples.
4. Lattice constant of the dispersoid.
5. Absorption.
6. X-ray analysis of the dispersoid isolated from the glassy matrix by chemical process.

VITREOUS LIMIT.

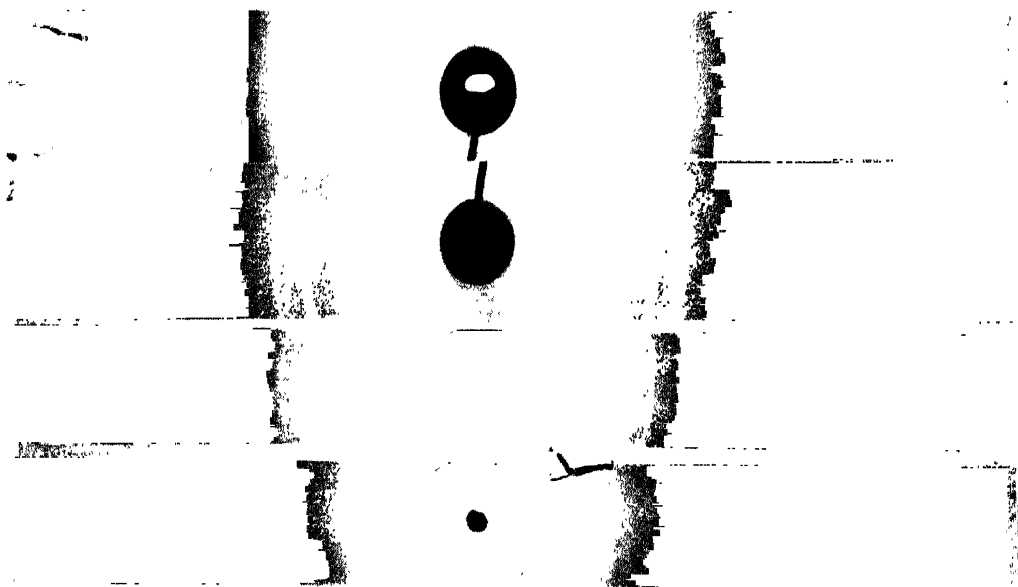
In the preparation of colloidal coloured glass specimen, utmost care is taken in selecting the composition, purity of the ingredients as well as the furnace temperature. All samples have been prepared in a Platinum crucible under identical condition at 1000°C . and consequently we can get a comparative idea about the vitreous limit of each glass series. All samples are kept in a vacuum desiccator. The gold content is determined idometrically and Platinum content colorimetrically by SnCl_2 method. The following results have been obtained.

Glass Composition.	Maximum concentration of dispersoid in wt. per cent.
Pt-Borax	2.8
Au-Borax	2.45
Pt- B_2O_3	2.39
Au- B_2O_3	2.12
Pt-Lindemann glass* ..	2.05

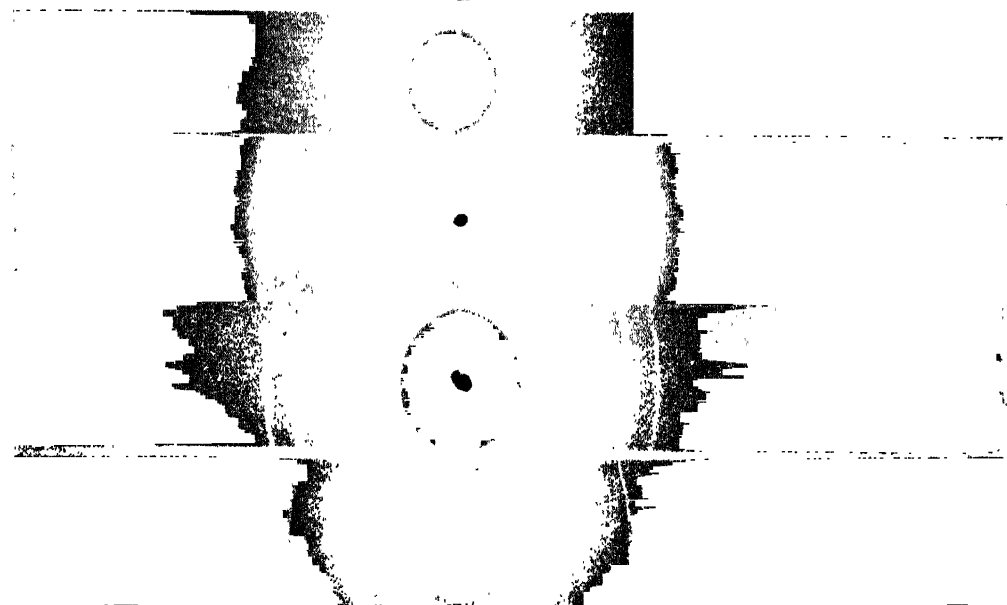
* Lindemann glass is formed by fusing together 17.8 parts by weight of Li_2CO_3 with 5.8 parts of BeCO_3 and 76.4 parts of Boric acid.

However, in each system the vitreous limit can be extended by the addition of oxide of Pb, Zn, Sn, etc., to the glass composition as well as by raising the furnace temperature. The addition of alkali oxide also extends the vitreous limit to a certain extent. It is also observed that the behaviours of the same solute

A



B



Pt Planes

\uparrow [111] \uparrow [200]
 \uparrow [220] \uparrow [311] \uparrow [222]
 \uparrow [400] \uparrow [331] \uparrow [420]

in different glass bases is not similar. In the present case it is found that the solubility of each dispersoid is greatest in the borax base.

COLOUR.

The Colour of gold specimen is pink and that of Pt is grey. Besides the oxide of Pb, Sn, Zn, etc., alkali oxide also increases the intensity of the colour to a considerable extent. Ordinarily the colour of the above glass specimens remains unaffected.

The colour of Au and Pt samples is very susceptible to the presence of some polar salts like alkali halide. It has been found that the glass batch containing a very small amount of KCl or NaCl in B_2O_3 glass fails to develop ruby colour. Again, it has been found that X-rays have no special action on the above glass specimens. Only the portion which has been exposed to X-rays for about 50 hours, shows a slight variation in colour from the rest of the portion. It will be interesting to mention the work of Galecki (1912) on the action of X-rays on gold solution where he found that the red colour of the solution was slightly altered, doubtless because the larger number of the fine particles remained unchanged.

X-RAY ANALYSIS OF GLASS SAMPLES.

X-ray was obtained from a Hadding-Seigbahn type of X-ray tube with Cu anti-cathode run at a voltage of the order of 60 Kv. with tube current of 10 milliamperes and the diffraction photographs were taken in a cylindrical camera of 3.90 cm. radius.

The X-ray diffraction pattern of some samples consists of some lines in addition to the diffuse band from the glass and the presence of lines in the X-ray picture indicates one or more crystalline phases in the glassy matrix. That observation gives a sharp contrast to the usual diffraction pattern of oxide glass.

It is well known that each crystalline substance has its characteristic set of plane spacings and the relative intensities of various reflections are also characteristic. The data thus obtained from the experimental specimen were compared with those of the likely substances. The lines on the X-ray picture can also be identified by finding by trial a unit cell such that the reflexion in the planes (hkl) will give the same value of $\sin^2\theta$ where θ is the Bragg angle as is found by the measurement of the film. As for example in the cubic crystal

$$\alpha^2 = \left(\frac{\lambda}{2}\right)^2 \frac{h^2 + k^2 + l^2}{\sin^2\theta}$$

where α = lattice constant,

λ = wave-length of X-ray,

h, k and l = indices of the plane

But in the case of a crystal of lower symmetry, the powder picture becomes very complicated. However, in the present case the crystal structure of dispersoid is cubic. Consequently, it is expected that the diffraction of each specimen will not be very much complex. Moreover the absorption coefficient of the B_2O_3 , Borax and Lindemann glass is low, so the nature and the state of existence of each dispersoid can be studied in detail. For the sake of convenience, colloidal coloured glass of each dispersoid has been studied one after another.

PLATINUM GLASS.

Pt has been dispersed in three glass bases such as Borax, B_2O_3 and Lindemann glass. Each set consists of many samples with concentration variation of noble metal. The composition of each sample is given in the following table.

In the case of Sp. 1 and Sp. 2 of each series, bands are quite prominent. The diffraction angles of those bands along with the data of the other samples of each series are given in the following table :—

Table 1

Glass Composition.	Sp. No.	Concentration of Pt in wt. per cent.	θ	Int.	θ	Int.
Pt-Borax	1	0.75	9° 21'	S	22° 30'	w(d)
	2	0.975	9° 21'	S	22° 30'	vw(d)
	3	1.25	9° 21'	S(d)		
	4	1.63	9° 21'	M(vvd)		
Pt-B ₂ O ₃	5	0.07	10° 55'	S	21° 35'	w(d)
	6	0.80	10° 55'	S	21° 35'	w(d)
	7	1.097	10° 45'	M(d)		
	8	1.62	10° 45'	M(d)		
Pt-Landmann	9	0.75	10° 39'	S	22° 20'	w
	10	1.02	10° 39'	S	22° 30'	w(d)
	11	1.75	10° 46'	S(d)		vw(d)
	12	1.825	10° 39'	MS(d)		vw(d)

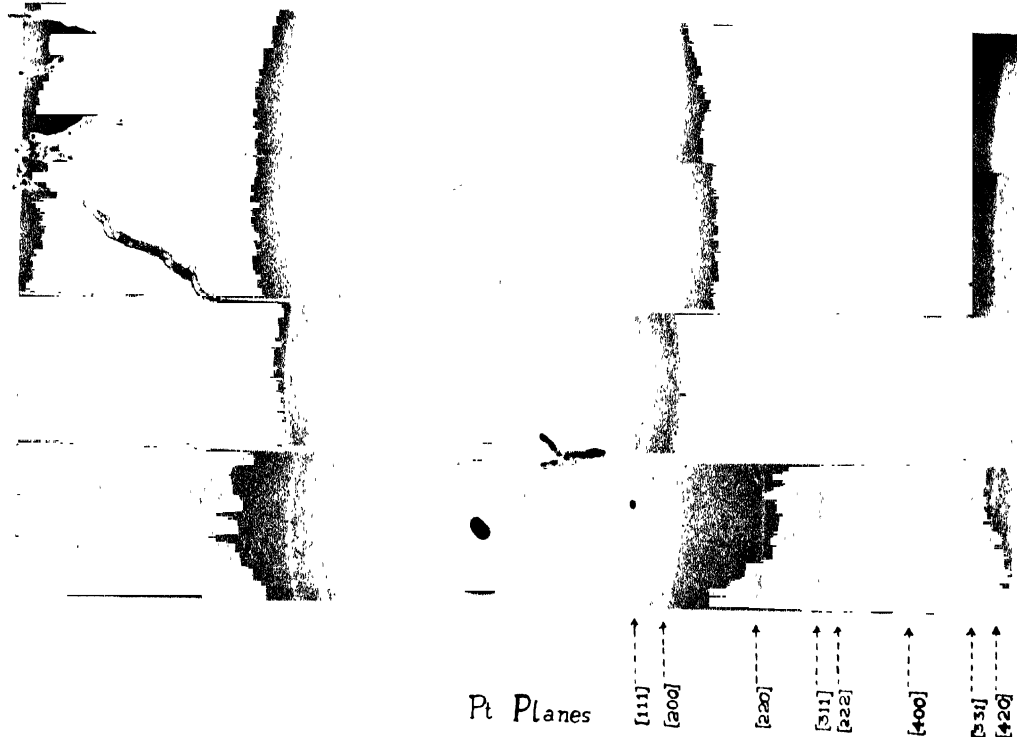
TABLE II.
Pt-Borax Systems.

[illegible]

TABLE III.
Pt-B₂O₃ Systems.

[illegible]

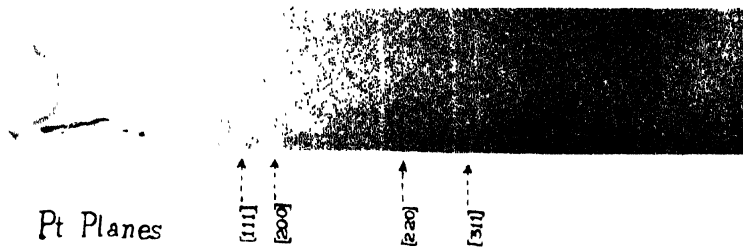
C



D



E



It is quite evident from Table I that the nature of the band in each glass specimen alters appreciably with the increase of Pt content in the glass base. The X-ray picture of the last sample of each series differs considerably from that of the first sample of the respective series.

The X-ray pictures of all samples are given in Plates VIII and IX. The diffraction angle with relative intensity of each line is given in Table II.

TABLE IV.

Pt-Lindemann Systems.

Pure platinum.			Sample 9		Sample 10		Sample 11		Sample 12	
Plane.	θ	Intensity.	θ	Int.	θ	Int.	θ	Int.	θ	Int.
(111)	20° 1'	1.00	20° 6'	s.	19° 50'	s.	20° 6'	s.	19° 50'	s.
(200)	23° 16'	0.30	23° 25'	m.s.	22° 51'	m.s.	23° 13'	m.s.	23° 4'	m.s.
(220)	33° 52'	0.16	33° 58'	m.w.	33° 51'	m.w.	33° 53'	m.w.	33° 43'	m.w.
(311)	40° 40'	0.16	40° 59'	m.w.	40° 45'	m.w.	40° 52'	m.w.	40° 38'	m.w.
(222)	43° 4'	0.03	42° 59'	w.	42° 59'	w.	43° 9'	w.	42° 52'	w.
(400)	51° 58'	0.03	51° 53'	w.	52° 9'	w.	51° 55'	w.	51° 55'	w.
(331)	59° 8'	0.03					59° 13'	w.	59° 2'	w.
(420)	61° 46'	0.02							61° 45'	w.

From the preceding tables it is quite evident that the broad lines present in the X-ray picture are due to the crystallites of Pt. As is quite natural the intensity of the lines increases with the rise of concentration of Pt content in the glass specimen, but along with it the nature of the band undergoes a distinct change—they become more and more diffuse with concentration. In the case of B_2O_3 series, there are some weak new lines which are due to the crystalline B_2O_3 .

GOLD RUBY GLASS.

Both Borax and B_2O_3 glass systems containing gold have been studied. Each set consists of a number of samples with the percentage variation of gold.

As in the case of Pt series, here too, the diffraction picture given in Plate X consists of both lines and bands. The diffraction angle of each band along with the relative intensity is shown below.

TABLE V.

Glass composition.	Sp. No.	Concentration in wt. per cent.	θ	Int.	θ	Int.	θ	Int.
Au-Borax	13	1.28	9° 21'	s.	14° 20'	w(d)	22° 24'	w.
	14	1.87	9° 21'	s.	14° 20'	w(d)	22° 24'	w.
	15	2.01	9° 21'	s.	14° 15'	v.v.w(d)	22° 35'	w.
Au- B_2O_3	16	0.05	10° 48'	s.	21° 25'	w.		
	17	0.40	10° 39'	s.	21° 30'	w.		
	18	1.56	10° 39'	s.	21° 45'	w(v.d.)		

It is quite evident from the preceding tables that the nature of the band is affected much by the presence of Au in the glass base and that is quite remarkable in the case of borax series.

The lines in the X-ray picture of Au series are weak in comparison with the Pt series and there is a much background scattering in each photograph. Nevertheless, the diffraction angle of each line (in $\text{CuK}\alpha$ radiation) has been compared with those of pure Au in the following table.

TABLE VI.
Au-Borax series.

Plane	Pure Au		Au Borax Sp. 13		Sp. 14		Sp. 15	
	θ	Int.	θ	Int.	θ	Int.	θ	Int.
(111)	19° 7'	1.00	19° 5'	m.w.	19° 0'	m.	19° 10'	m.
(200)	22° 127'	0.53	22° 24'	w.	22° 24'	m.w.	22° 24'	m.w.
(220)	32° 21'	0.33					32° 39'	w.
(311)	38° 53'	0.40					39° 5'	w.
(222)	41° 2'	0.09					41° 9'	v.w.
(400)	49° 7'	0.03						
(331)	55° 27'	0.09						
(420)	57° 48'	0.07						

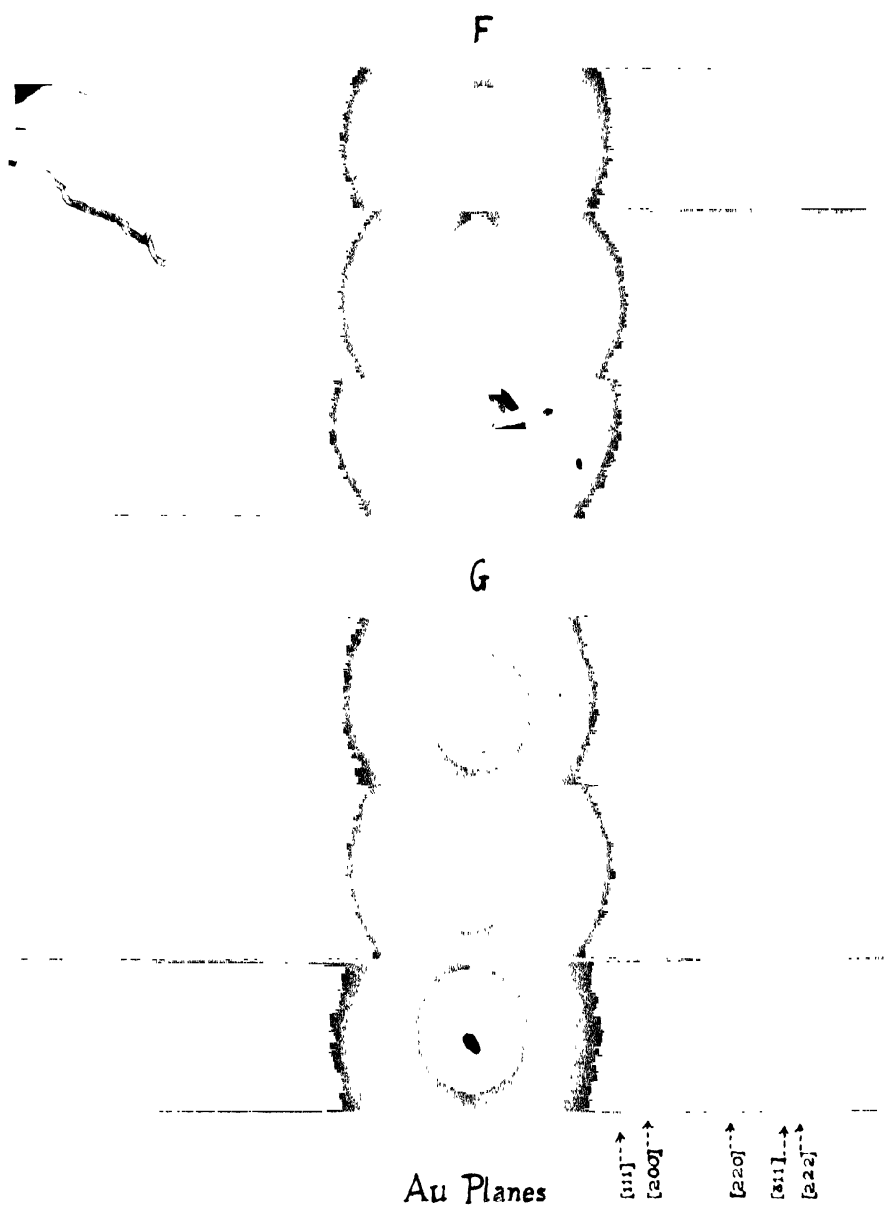
TABLE VII.
Au B_2O_3 series.

Plane.	Pure Au		Sp. 16		Sp. 17		Sp. 18	
	θ	Int.	θ	Int.	θ	Int.	θ	Int.
(111)	19° 7'	1.00	19° 5'	v.w.	19° 5'	m.w.	19° 5'	s.
(200)	22° 17'	0.53			22° 9'	w.	22° 17'	m.s.
(220)	32° 21'	0.33			32° 17'	v.w.	32° 9'	m.
(311)	38° 53'	0.40					38° 47'	m.
(222)	41° 2'	0.09					41° 2'	m.w.
(400)	49° 7'	0.03					49° 13'	w.
(331)	55° 27'	0.09						
(420)	57° 48'	0.07						

From the preceding tables, it is quite evident that the lines present in the diffraction photograph of the above series are due to gold. Lines are usually weak. In the case of B_2O_3 series, there are some weak lines due to B_2O_3 .

LATTICE CONSTANT OF THE DISPERSOID.

The systematic errors involved in measuring the ' d ' values by the X-ray diffraction method have been studied by various workers. The errors listed are mainly due to (i) Film shrinkage, (ii) Eccentricity of the sample, and (iii) Absorption. In the present case, the ' d ' value of the dispersoid in the glass system has been determined by the Internal Mixture method. As for example, Sp. 1 of Pt-Borax series is mixed with Al powder in the weight ratio 1 : 1 where Al served as a



standard substance. The X-ray picture of the cylindrical form of the above mixture is taken in a cylindrical camera of 5.0 cm. radius. The ' d ' value of each line of Pt is calculated with reference to the ' d ' value of Al which serves as a check in the value of radius of the camera in the equation where x = distance between a pair of lines.

$$\theta^\circ = \frac{x}{4r} \times 57.3 \quad r = \text{radius of the camera.}$$

The diffraction angle of each line of Pt is in good agreement with the diffraction angle of Pt calculated from the lattice constant of Pt.

TABLE VIII.

Experimental.			
θ	Int.	Diffraction angle of the element.	Plane.
19° 18'	v.s.	Al	(111)
20° 1'	m.	Pt	(111)
22° 24'	s.	Al	(200)
23° 16'	m.w.	Pt	(200)
32° 33'	m.s.	Al	(220)
33° 52'	w.	Pt	(220)
39° 12'	m.s.	Al	(311)
40° 49'	w.	Pt	(311)
41° 14'	m.w.	Al	(222)
43° 4'	v.w.	Pt	(222)
49° 37'	w.	Al	(400)
51° 58'	v.v.w.	Pt	(400)

ABSORPTION.

So far we have discussed about the nature of the crystalline phase in the glassy matrix. It is also pointed out that in many of the photographs one or more bands appear. Moreover, pure glass base such as B_2O_3 , Borax, Lindemann glass, etc. gives rise only to bands in the diffraction pattern and the values with intensity relation are given in the following table:—

TABLE IX.

Glass.	θ	Character.	θ	Character.	θ	Character.
Borax ..	9° 18'	Sharp ..	14° 10'	Fairly sharp ..	22° 27'	Sharp.
B_2O_3 ..	10° 48'	Sharp ..	21° 25'	Weak but well-defined.		
Lindemann ..	16° 55'	Sharp ..	21° 24'	Weak but well-defined.		

Although in no case of the glass specimens, the content of the dispersed phase hardly exceeds about 2.5 per cent but from the pictures of the plate it can be readily seen that the bands fade out with the rise of Pt content. Similar observation is also made in other series such as Au specimens.

All the X-ray pictures have been taken in the same camera with the same radius of the sample stick, consequently with the same volume of the substance irradiated. The fading of the bands for stronger concentrations show that absorption plays a leading rôle in quenching the intensity of the bands in the X-ray pictures of the glass specimens containing Au or Pt as a dispersoid. Thus at an appreciable concentration of the dispersoid its high mass absorption overrides the low absorption coefficient of glass base, which contains very large percentage of weightage.

X-RAY ANALYSIS OF THE DISPERSOID ISOLATED FROM GLASSY MATRIX.

The crystalline phase was separated from the glassy matrix with the help of HF. The effect of HF was to dissolve the glass, setting free the gold particles which were not attacked by HF. A typical sample of Pt - B_2O_3 series—Sp. 6 was taken and about 5 gms. of that sample was treated in a Pt basin over water-bath. In this way Platinum was isolated in an unaffected state from the glassy matrix with distilled water. The X-ray picture of the isolated Platinum from the same specimen is given in Plate No. IX. The X-ray data are given in the following table:—

TABLE X.

Int.	θ	θ	Int.
1-00	20° 1'	19° 55'	s.
0-3	23° 16'	23° 2'	m.s.
0-16	33° 52'	33° 52'	m.
0-16	40° 49'	40° 52'	m.
0-03	43° 4'	42° 58'	m.w.
0-03	51° 58'	52° 0'	m.w.
0-03	59° 8'	59° 15'	w.
0-02	61° 46'	61° 50'	w.

From the width of the line of the isolated crystallite, it is quite evident that the particle is of colloidal size. Further it is found that besides the lines of Pt, there are some weak lines in the X-ray picture of the isolated specimen.

The observations detailed above show that in the X-ray diffraction photographs due to coloured glasses produced by the solution of Au and Pt in boric oxide, borax or Lindemann glasses consist of bands accompanied by fairly sharp lines. The lines have the same spacings as those present in the powder photographs of the dispersoid materials. For very weak concentrations of the dispersoid the lines are usually absent apparently due to too weak intensity. For much stronger concentrations sometimes only lines are found in the X-ray picture. This is evidently due to strong absorption by the dispersoid. All these glass samples showed no sign of devitrification when examined under a polarizing microscope and a glass slab of appreciable thickness showed no sign of milkiness. So it is evident that the lines are due to the dispersoid and their sharpness indicate that they are of colloidal dimensions. Half-intensity widths of these lines are being determined in order to find out the average sizes of these colloids.

The whole work has been carried out under the guidance of Prof. K. Banerjee at the Indian Association for the Cultivation of Science.

I am thankful to the Council of National Institute of Sciences of India for the award of an I.C.I. Research Fellowship to me. Thanks are also due to Prof. S. K. Majumder for the kind interest in the work.

SUMMARY.

The nature of the colloidal particles of Au and Pt in glass samples of B_2O_3 , borax and Lindemann glass and their influence on the structure of the glass have been investigated. The method of formation, vitreous limit, colour and the other interesting properties of the above glass systems have been also discussed. X-ray photographs of the samples reveal the presence of broad lines of the noble metals besides the diffuse haloes of glass.

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SARCANDRA IRVINGBAILEYI,
A NEW SPECIES OF VESSELLESS DICOTYLEDON FROM SOUTH INDIA

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The re-establishment of the generic rank of *Sarcandra* Gardner (1846) of the Chloranthaceae as distinct from the genus *Chloranthus* Swartz (1787) of the same family has been proposed in a recent publication (Swamy and Bailey, 1950). In this contribution are also provided arguments that warrant such a taxonomic re-adjustment. In the course of assembling material for a detailed investigation of the comparative anatomy, morphology, and systematic relationships of the Chloranthaceae, which is in progress, herbarium specimens collected from South India and Ceylon were found to differ markedly from the two recognised species of the genus *Sarcandra*, *S. glabra* (Thunb.) Nakai, and *S. hainanensis* (P'ei) Swamy and Bailey.

There appears to be an opinion in some quarters that the vesselless dicotyledons are a small and insignificant group that lack evolutionary diversification. Although *Trochodendron*, *Tetracentron*, and *Amborella* are the only three genera that are represented by a single species in each genus, they exhibit among themselves a high degree of exomorphic diversification in regard to vegetative and reproductive structures. The nearly 88 species of the Winteraceae are spread in six genera and the smallest genera of the family (*Pseudowintera* and *Exospermum*) contain two species in each; three other genera, from six to 30 species; the genus *Drimys* includes 40 species and 12 varieties in two distinct taxonomic sections. Geographically, the vesselless dicotyledons at present have a wide distribution,—Australia, Malaysian Islands, Malay Peninsula, India, Central China, and Japan in the Old World, and South America in the New World. Furthermore, recent taxonomic studies, particularly on the flora of China, of Malasia, and other Pacific Islands have provided an excellent illustration of new and remarkably interesting plants coming to light with almost every botanical exploration in these areas. The recent discovery of two more genera of vesselless dicotyledons—*Amborella*, of the Amborellaceae (Bailey and Swamy, 1948) and *Sarcandra*, of the Chloranthaceae (Swamy and Bailey, 1950)—while exemplifying the realization of van Tieghem's (1900) prophecy, gives a sanguine hope of finding still newer and more diversified morphological types in future. Such considerations as these reflect that the vesselless dicotyledons cannot be dispensed away as an insignificant inconsequential group, but they are a flourishing, highly heterogeneous assemblage both in size and in geographic extent.

While annotating the herbarium specimens examined, I have used the following ~~abbreviations~~ ^{abbreviations}: BM—British Museum (Natural History); G—Gray Herbarium; K—Kew Herbarium; MH—Madras Herbarium (Coimbatore); MICH—Michigan University Herbarium; NY—Herbarium of the New York Botanical Gardens; UC—Herbarium of the University of California (Berkeley).

Almost all specimens of this new species that are deposited in American and Indian herbaria have been sectioned and examined. The material for the accompanying illustrations has been selected from *Barber 6033* and *Erlanson 5439*.

Description.

Stem.—The oldest specimen of stem available for sectioning measures 0.5 cm. in diameter and shows a growth of two years (Fig. 13). The termination of the cambial activity towards the end of the first year is marked by a concentric zone of tracheids (two to four radial rows) that present a conspicuously narrow radial diameter (Figs. 8, 9).

Generally, the tracheids are arranged in relatively undisturbed radial series from the primary xylem outwards. When two radial rows of tracheary cells lie adjacent to one another in the region of the primary xylem, the mutually contacting radial walls appear to be placed at an oblique angle in relation to the tangential walls as seen in transections (Figs. 8, 9); however, with the diametrical increase of the secondary xylem, not only a more or less rectangular cross-sectional outline is attained by the tracheids, but also a uniform radial alignment.

The imperforate tracheary cells of the secondary xylem within the first year's growth zone are as long as two millimeters, and the ends overlap those of the vertically adjacent members over an extensive area. These features provide a remarkable similarity to the corresponding structures, not only of other species of *Sarcandra*, but also of other living vesselless dicotyledons,—*Trochodendron*, *Tetra-centron*, *Amborella*, and the genera of the Winteraceae.

The tracheids of the first formed part of the primary xylem are relatively narrower in cross-sectional area and possess typical helical thickenings. Those of the metaxylem and of the subsequently formed earlier part of the secondary xylem exhibit larger lumina and predominantly uniseriate scalariform pitting on the radial facets. The successively formed tracheids gradually become narrower again and the intertracheary pits correspondingly assume circular outlines (Fig. 11). The early formed tracheids at the beginning of the second growth season possess approximately the same cross-sectional area as those formed later. However, the inter-tracheary pitting of the early formed tracheids (two to three rows) is scalariform in contrast to the circular bordered pitting of the later formed ones: the tracheids in between these two zones show a more or less transitional series. On the whole, the inter-tracheary pitting is largely confined to the radial walls.

The inter-xylary parenchyma is very scantily developed, a feature that appears to be a general tendency in the other species of *Sarcandra* also (Swamy and Bailey, 1950). Among the specimens of the present species, the one illustrated in this paper (Figs. 8, 9, from *Erlanson 5489*) shows an almost total absence of parenchyma; and *Gamble 18395*, a rather meagre development. In the latter specimen, it is diffusely distributed in the growth layer. As in other species of the genus, as also in *Trochodendron*, *Euptelea* and probably in other dicotyledons, the wood parenchyma cells are arranged in pairs, the total width of a pair being equal to the tangential diameter of the tracheids.

The ray system involves two distinct types of organization. Vertically extensive sheets of parenchymatous tissue of six to eight cells width radiate from the inter-fascicular parts of the eustele and constitute the primary multiseriate rays (Fig. 8). These rays consist wholly of vertically elongate cells as seen in a tangential section (Fig. 10). From the intra-fascicular regions single-celled rows of parenchymatous cells extend towards the periphery as seen in transections (Figs. 8, 9), and these constitute the uniseriate rays. The uniseriate rays are also considerably tall, and the component cells vertically elongate. Occasionally, the body of this kind of ray may be biseriate.

The structures of the relatively thin bark are badly collapsed due to drying, and the only feature that could be observed is the groups of phloem fibres confronting the fascicular sectors of the secondary xylem (Fig. 8). The periderm takes its origin superficially.

Note.—The decussate phyllotaxy of the young leaves is carried over to the mature condition without alteration. The bases of the petioles of opposite leaves fuse to form a conspicuous vagina-shaped sheath. From the rim of the sheath emerge denticular processes of stipular nature. The petiole contains five vascular strands (Fig. 12), two of them larger and placed in an abaxial disposition; the other three strands are conspicuously smaller and are located alternately with the larger. The two larger strands are concerned in the major vascularization of the lamina and usually remain distinct for a greater distance in the costa. The small strand between the larger ones gradually becomes thinner, traverses as far as the middle distance of the costa, and finally either fuses with one of the larger strands, or disappears. The two adaxially situated smaller strands are also rather weakly developed and traverse along the margins to about half the length of the leaf.

At lower levels of the stem, the small, intervening median strand is seen to arise by the fusion of two minor branches of the larger strands. The latter in turn remain separate at still lower levels and ultimately fuse with independent parts of the eustele (Fig. 12). The four smaller adaxially situated strands of opposite leaves also originate independently from four separate systems of the eustele at lower levels of the stem, although the strands (later differentiating as laterals of a corresponding side) of opposite leaves may be fused for a short distance in the axis. Thus it is clear that no vascular strand of the leaf arises as a *dichotomy* of any one single strand of the eustele of the axis, but originates *independently from separate systems*. It should also be noted that of the five leaf strands, the three medians (two larger ones and the intervening smaller one) are related to a single 'gap' and that the two smaller adaxially situated strands to independent 'gaps', a feature sporadically seen with some variations in dicotyledons, e.g., Calycanthaceae, *Nyctanthes*, some genera of the Compositae, etc.

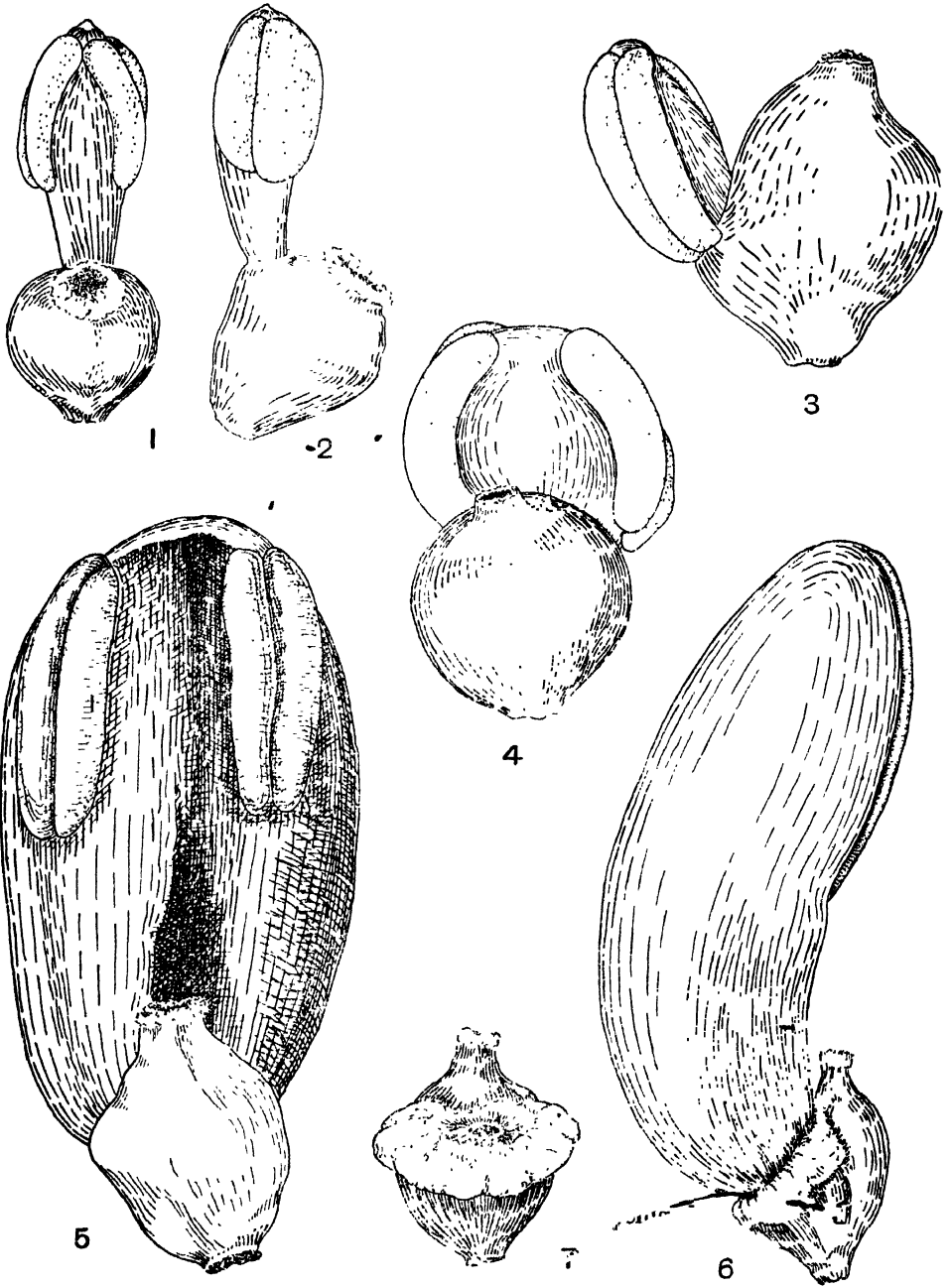
Reproductive structures.—The inflorescence is terminal and consists of three main branches, the median one again giving rise to three branchlets. About 10 flowers are borne on each branch. The flower is naked, sessile, hermaphroditic, and is subtended by a somewhat carinate and persistent bract. The solitary urn-shaped carpel lodges a single orthotropous ovule hanging from the apex of the locule. The large fleshy stamen is attached at about the middle height on the abaxial side of the gynoeceium (Fig. 6). At the junction of the stamen with the carpel, the latter shows a deformation in the form of a pronounced cushion (Figs. 6, 7). The stamen is oblong, abaxially concave, slightly sickle-shaped. The four thecae are disposed in pairs on the adaxial surface of the microsporophyll towards its distal end, and vertically extend towards the base to about half the distance (Fig. 5). The mature pollen grains are colpate with a coarsely reticulated pattern of the exine.

The exomorphic characters exhibited by the reproductive structures of the specimens under consideration indicate that these plants are significantly different from *S. glabra* (Thunb.) Nakai and *S. hainanensis* (P'ei) Swamy and Bailey. Therefore, the creation of a new species for the allocation of these plants is warranted. The name and the technical description of the new species may be given as follows:

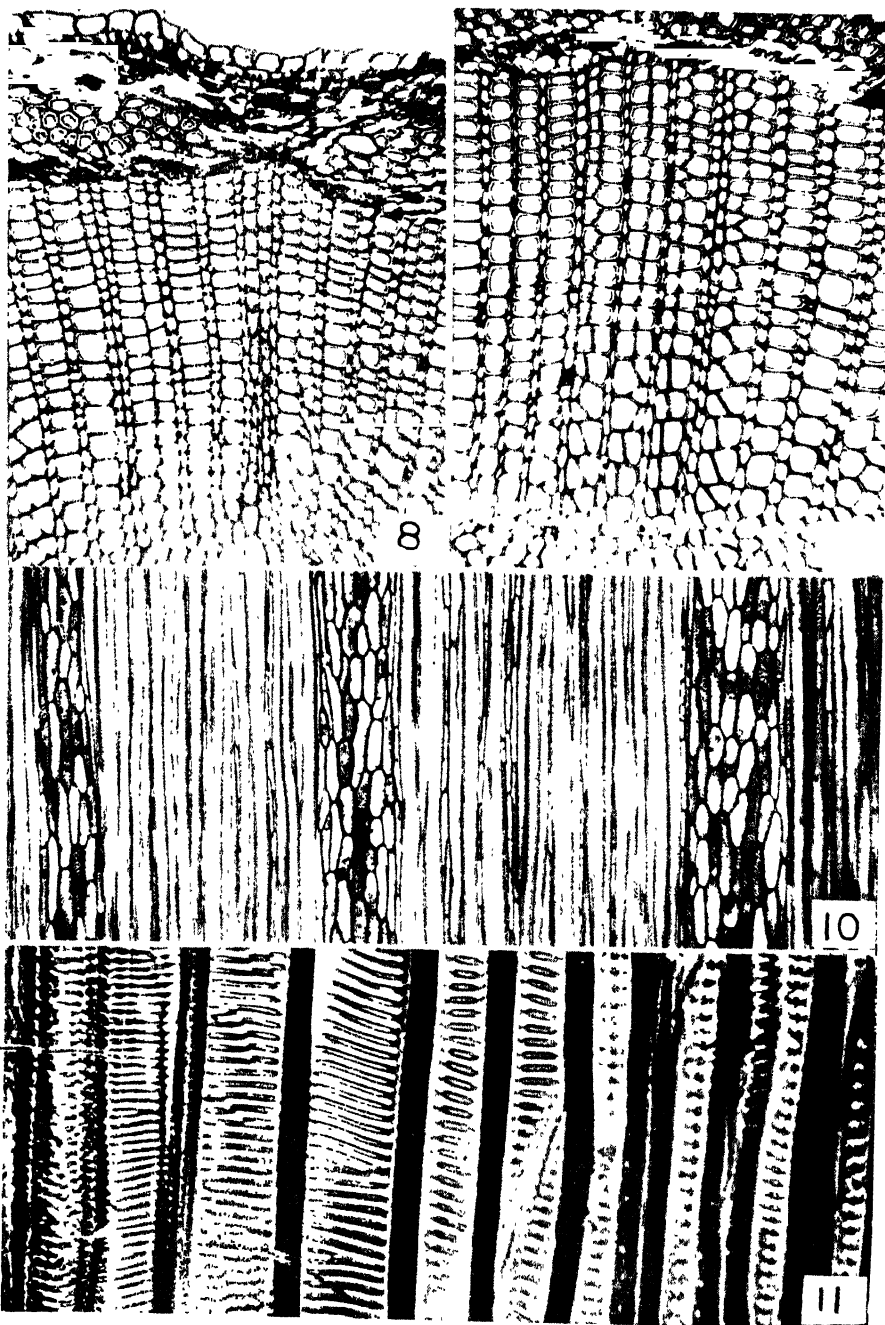
***Sarcandra Irvingbaileyi* sp. nov.**

Sarcandra chloranthoides Wight, in Wight Ic. VI: t. 1946. 1853. non *S. chloranthoides* Gard. Calcutta Jour. Nat. Hist. 6: 296. 1853. *S. glabra* (Thunb.) Nakai, Fl. Sylv. Koreana 18: 17. t. 2. 1930.

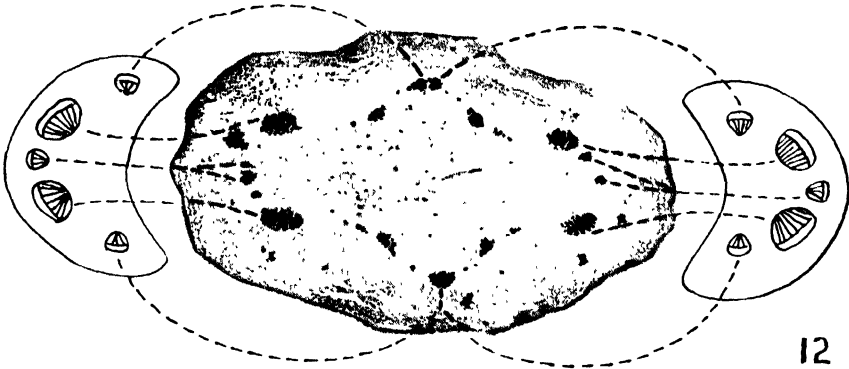
Frutex, 1-2 m. altus, glabratus; lignum primarium et secundarium homoxylum; folia opposita, breviter petiolata; petiolus 0.5-1.0 cm. longis, connatis ad basim atque vaginum efformantibus; lamina 6.0 cm. × 3.0 cm., 11.5 cm. × 4.5 cm. 20.0 cm. × 8.0 cm. longa et lata, elliptico-ovata, apice mucronata; base cuneata, margine crasse glanduloso-serrato praedita; stipulae minutae, 1 mm. longae, lanceo-



Figs. 1-7.



Figs. 8-11.



12

FIG. 12.



13

FIG. 13.

latae. Inflorescentia terminalis, panniculata, pedicellis primariis tribus, quorum inedius in tres interum dividiter; spicae singulae 2.0–2.5 cm. longae; bractae singulae, 1.5–2.0 mm. longae, carinatae, persistentes ad rachedem horizontalis; flores hermaphroditi, sessiles; perianthium nullum; stamen 1, oblongum, in facie adaxialf concavum, in facie abaxiale convexum, amplum et carnosum, 4.5–5.0 mm. longum, 1.75–2.5 mm. latum, rachidi in facie abaxiale gynoeceii insertum, parallelum et paene tangens; sporangia inparibus binis, 1.5–2.0 mm. longa, juxta staminis apicem; pollinis grana acolpata, cum extine crasse reticulato; pistillium solitarium, sessile, plus minusve ovoideum, pulvino prominenti abaxiali in staminis basi; stylus nullus; stigma subcapitatum; ovarii loculi singuli, ovula singula, orthotropa, ab apice loculi suspensa. Fructus non visus.

Specimens examined.

SOUTH INDIA: Madras Presidency, with no specific locality, *Wight 2509* (G).

Travancore State—Ponmudi, Merchiston Estate, edge of jungle, *Erlanson 5489* (MICH., N.Y.), March 3, 1934, alt. 933 m.

Tinnevely District—Kalinayalpil, *Barber 3063* (K, MH), June 1, 1901; Kanikatti, *Barber 378* (K, MH), June 6, 1899; Naterikal to Sengalteri, no collector's name, Madras Herbarium No. 44265 (MH), September 24, 1916; Courtallum, ex herb. *Bourne*, no number, August, 1899.

Madura District—Pulney Mountains, as illustrated in *Wight. Ic. VI. t. 1946. 1853.*

Coimbatore District—Anamalais, *Beddome 6079* (MH), alt. 666 m.; *Beddome 6710* (MH), alt. 1,000 m.; Udumanparai, *Barber 5856* (MH), May 11, 1903; Shola above Andiparai, *Barber 6033* (MH, TYPE), June 2, 1903; Ibex Hill Shola, Fischer, no number (K), May 24, 1913, alt. 1,533 m.

Malabar District—Attapadi Hills, Adumudi Shola, *Fischer 2503* (K), January 28, 1911, alt. 1 000 m.; Wynad, *Beddome 6708* (BM).

Nilgiri District—? Concon Ghat, no specific locality, *Gamble 18395* (K), October, 1886, alt. 833 m.

CEYLON: With no specific locality, *Walker 207* (K); Gammaduva, in the jungle, *Alston 673* (UC), June 6, 1927.

Artificial key for the identification of the putative species of Sarcandra.

Although *Sarcandra Irvingbaileyi* is similar to *S. glabra* (Thunb.) Nakai and *S. hainanensis* (P'ei) Swamy and Bailey in several vegetative and anatomical characters, the three species can be readily identified by their floral structures as follows:

Stamen sessile, discoid, circular to broadly—elliptic in surface view, 2.0×2.0 mm., thecae latrorse, as long as the microsporophyll (Figs. 3, 4)—*S. hainanensis*.

Stamen stalked, somewhat cylindrical with slight dorsiventral flattening, thecae 1/3–2/3 the length of the microsporophyll, and always situated nearer to the apex.

Microsporophyll small, 2.0×1.0–2.5×1.75 mm., club-shaped, thecae generally latrorse, less frequently introrse; orientation of the stamen nearly horizontal to the rachis; ovary without an abaxial cushion (Figs. 1, 2)—*S. glabra*.

Microsporophyll large, 4.0×2.0–5.0×2.5 mm., very fleshy, oblong, adaxial surface concave, thecae always introrse, orientation of the stamen parallel to the rachis; ovary with a pronounced cushion on the abaxial side at the point of attachment of the stamen (Figs. 5–7)—*S. Irvingbaileyi*.

SUMMARY.

An examination of vast collections of the genus *Sarcandra*, deposited in several herbaria of the United States of America, Great Britain, and India indicate that specimens coming from South India differ significantly in the exomorphic floral characters from other recognized species of the genus, *S. glabra* and *S. hainanensis*, and therefore warrant the establishment of a new species for the accommodation of these plants.

Attention is drawn to the vesselless nature of the xylem of these plants, and its structural characteristics are described. This important feature, together with data obtained from nodal anatomy and from comparative morphology fall within the range of variability exhibited by the genus *Sarcandra*. However, the specimens distinguish themselves significantly from other known species of the genus in the possession of an unusually large stamen and of a marked cushion-shaped deformation on the abaxial side of the carpel.

The name *Sarcandra Irvingbaileyi* sp. nov. is proposed for the reception of these plants and the diagnostic features of the species are described, together with annotations of herbarium specimens examined.

ACKNOWLEDGEMENTS.

I thank the authorities of the many Institutions mentioned under the list of specimens examined for having extended to me the privilege of examining their respective collections. I am grateful to the officers of the Madras Herbarium (Coimbatore) for their cordial co-operation that has rendered the completion of this contribution. With deep gratitude I record the encouragement given to me by the National Institute of Sciences of India through the award of a Research Fellowship which has enabled me to carry out this investigation. To the Madras University and to Prof. T. S. Sadasivan I am much obliged for making available to me all facilities to work in the University Botany Laboratory.

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LEGEND TO FIGURES.

FIGS. 1-7.—Fig. 1. *Sarcandra glabra*, flower showing stamen and pistil, as seen from adaxial side. Fig. 2. Same, as seen from a side. Fig. 3. Flower of *Sarcandra hainanensis*, side view. Fig. 4. Same, adaxial view. Fig. 5. *Sarcandra Irvingbaileyi*, adaxial view of the flower. Fig. 6. Same, side view. Fig. 7. Same, from the adaxial side showing the pronounced cushion after removal of stamen. All figures are drawn to the same scale.

FIGS. 8-11.—Fig. 8. *Sarcandra Irvingbaileyi*, transection of a sector of stem showing a multiserial ray, phloem fibres confronting the fascicular parts of secondary xylem, etc., ($\times 84$). Fig. 9. Same, a fascicular part showing predominantly uniserial rays ($\times 84$). Fig. 10. Tangential section of early formed secondary xylem showing the multiserial and uniserial rays ($\times 50$). Fig. 11. Inter-tracheary pitting of primary (left hand side) and of early formed part of secondary xylem ($\times 380$).

FIGS. 12, 13. *Sarcandra Irvingbaileyi*.—Fig. 12. Transection of a young stem at the nodal level, indicating the relationship of leaf strands to the vascular bundles of the stem ($\times 62$). Fig. 13. Transection of an older stem ($\times 18$).

SOME OBSERVATIONS ON THE EMBRYOLOGY OF *DECAISNEA* *INSIGNIS* HOOK. ET THOMS¹

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INTRODUCTION.

As suggested in a previous paper (Swamy and Bailey, 1949), the families of ranalian affinities as broadly conceived by Engler and Prantl may be regrouped to advantage under at least two major categories: (1) having monocolpate pollen or phylogenetically modified types of such pollen, and characteristic secretory cells ('ethereal oil cells'), and (2) having tricolpate pollen or types derived therefrom, and no 'ethereal oil cells'. In the latter group belong, among others, Ranunculaceae, Berberidaceae, Lardizabalaceae, and Menispermaceae. These four families are generally assumed to exhibit closer relationship among themselves than with other families of the category. In view of the recent results that are being obtained by comparative morphological and anatomical studies on the ranalian families, it appears very desirable to supplement data from embryological investigations on these and other families of the Ranales.

The only information available on the embryological characters of the Lardizabalaceae are those provided by the casual accounts of Vesque (1879) on *Holboellia latifolia* and of Vesler (1913) on *Akebia quinata*. Both the authors report the formation of a parietal cell in the ovules of the respective species investigated by them and Vesler's slightly extended observations, although inadequate, concern the development of the embryo sac and of pollen grain.

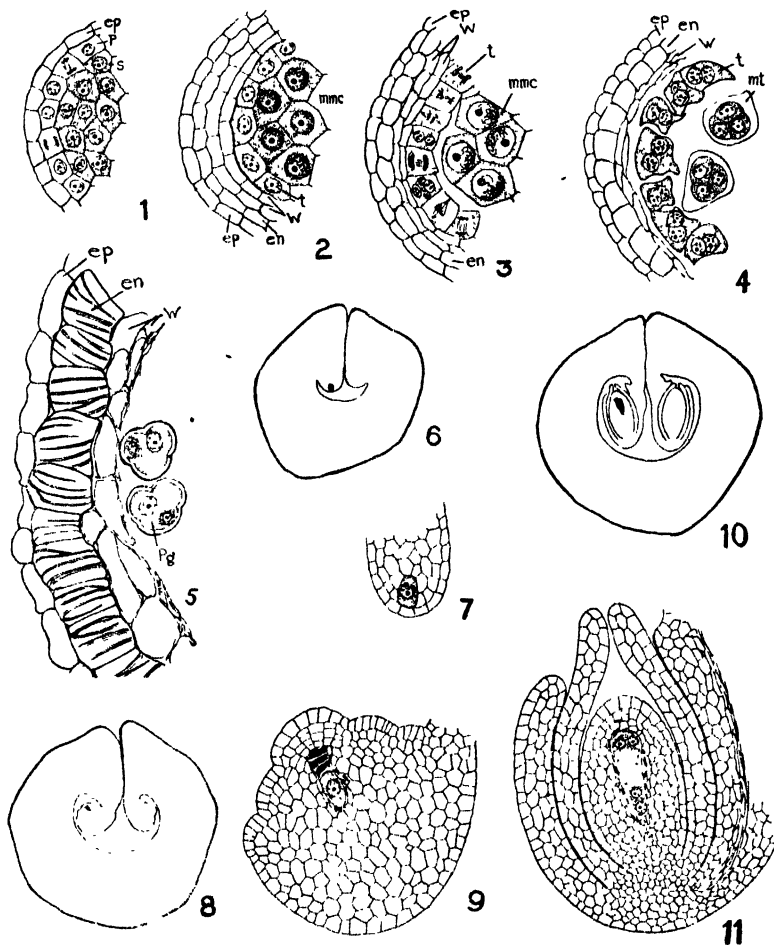
OBSERVATIONS.

Development of the pollen grain.—Fig. 1 represents an early stage in the development of an anther. The outermost layer of cells is the epidermis (*ep*) and the second is obviously a derivative of the archesporium and functions as the primary parietal layer (*p*). The cells towards the interior are arranged in a compact mass and constitute the sporogenous tissue (*s*). The parietal row of cells gives rise to four layers: the outermost differentiates into endodermis (Figs. 2-5, *en*); the innermost functions as tapetum (Figs. 2-4, *t*); the middle two layers constitute the wall tissue (Figs. 2-5, *w*). When the microspore mother cells are passing through mid-prophasic development, the tapetal cells become binucleate (Fig. 3, *t*) and reach maximum activity when microspore tetrads are organized (Fig. 4, *t*). At this stage the individual cells of the tapetum exhibit a less angular contour, a coarsely granular and vacuolate cytoplasm, and prominent nuclei. Their activity appears to slow down gradually and the structure degenerates by the time the microspores are organized. In the mature anther the epidermis persists as also one or irregularly two layers of wall tissue in a somewhat crushed condition in addition to the well developed endothecium (Fig. 5); however, the cells are devoid of protoplasts. The sequence of stages in the development of pollen grains does not present

¹ The material was obtained in 1949 from a plant under cultivation in the Arnold Arboretum, Massachusetts, U.S.A.

any unusual features. Thus, the meiotic divisions take place in a simultaneous manner; the disposition of microspores of a tetrad is tetrahedral; the pollen grains are two-celled at the shedding stage (Fig. 5).

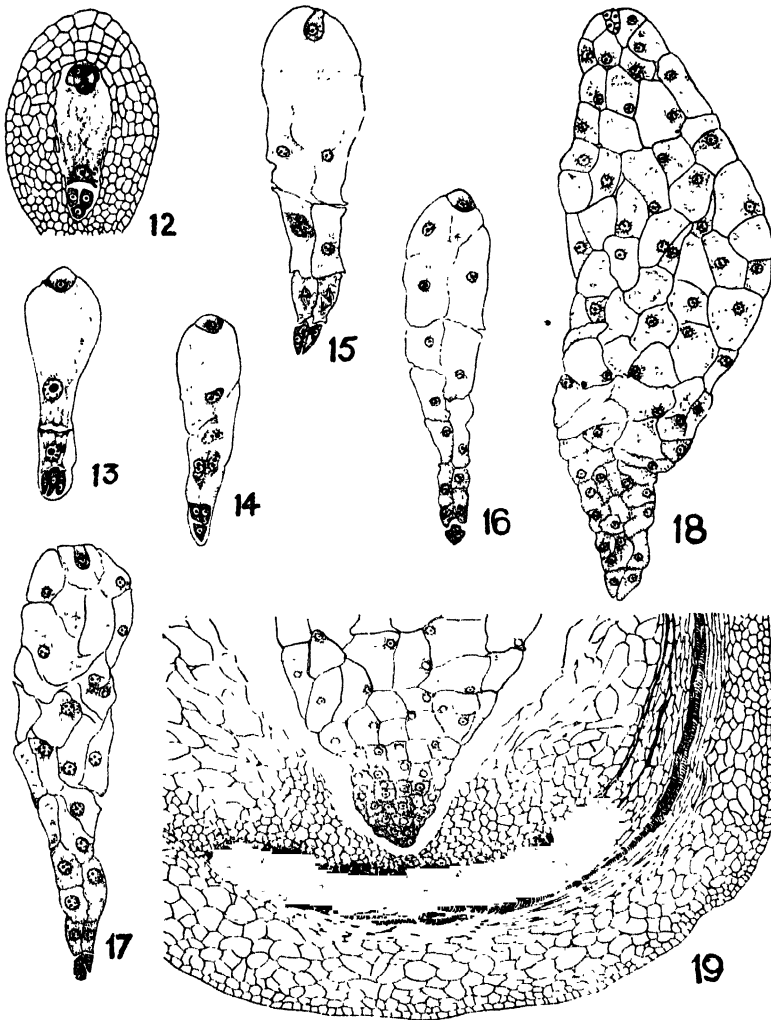
Development of the embryo sac.—The ovules are arranged in two longitudinal series, considerable distance away from the actual margins of the megasporophyll



Figs. 1-11. Figs. 1-5. Transections of a part of anther locule illustrating successive stages in the development of anther wall and pollen grain, $\times 50$. *en*—endodermis; *ep*—epidermis; *mmc*—microspore mother cells; *mt*—microspore tetrad; *p*—parietal layer; *pg*—pollen grain; *s*—sporogenous tissue; *t*—tapetum; *w*—wall layers. Fig. 6. Outline of transection of carpel, $\times 12.5$. Fig. 7. Ovular primordium from Fig. 6 enlarged to show the archesporial cell, $\times 32.5$. Fig. 8. Outline of transection of carpel slightly older than in Fig. 6, $\times 12.5$. Fig. 9. Ovule in Fig. 8 enlarged to show the origin of integuments and linear tetrad of megaspores, the three micropylar ones degenerating, $\times 32.5$. Fig. 10. Outline of transection of carpel at the time of pollination, $\times 12.5$. Fig. 11. Longisection of ovule from Fig. 10, showing the organization of micropyle and four-nucleate embryo sac, $\times 32.5$.

(Fig. 10; see also Bailey and Swamy, 1951). The ovule primordium arises as a tiny protuberance directed towards the dorsal side of the carpel and even at an early stage as this, the single hypodermal archesporial cell stands fully differentiated (Figs. 6, 7). Subsequent growth results in a 180° curvature of the longitudinal axis of the nucellus and integuments so that about the four-nucleate

stage of the embryo sac the ovule attains typically anatropous position (Figs. 10, 11). The two integuments are initiated simultaneously with sporogenesis and their pre-fertilization development is completed when the female gametophyte is tetra-nucleate (Fig. 11). The inner integument is uniformly of three cell layers thickness and the outer, at this stage, consists of four cell layers.



FIGS. 12-19. Fig. 12. Longisection of nucellus prior to fertilization, showing mature embryo sac, $\times 32.5$. Fig. 13. Two-celled endosperm, $\times 32.5$. Figs. 14-18. Representative stages in the subsequent development of endosperm, Figs. 14-16, $\times 32.5$; Fig. 17, $\times 22.5$; Fig. 18, $\times 17.5$. Fig. 19. Longisection of chalazal part of ovule showing the position of darkly staining pad of cells and its relation to other tissues of ovule, $\times 12.5$.

The archesporial cell divides by a periclinal wall to form perietal and sporogenous cells. The former by successive divisions builds up a parietal tissue of three or four layers, and the latter functions as the megaspore mother cell. A

typical linear tetrad of megaspores is formed as a result of meiotic divisions; the chalazal megaspore matures into an eight-nucleate embryo sac (Figs. 9, 11, 12). The antipodal nuclei organize into cells, and persist without any morphological change during post-fertilization development until as late a stage as in Fig. 17. The polar nuclei fuse before fertilization and the resulting nucleus occupies a constant position nearer to the antipodal group (Fig. 12).

Endosperm.—The triple-fused primary endosperm nucleus divides *in situ* and promptly a cell membrane is organized between the daughter nuclei. This results in the partitioning of the embryo sac into a larger micropylar and a smaller chalazal chambers (Fig. 13). Both the compartments appear to have an equal share in the building up of endosperm. Nuclear divisions in earlier stages proceed more or less simultaneously in the two chambers and walls formed during divisions intersect one another in all planes so that a distinction between the derivatives of the two chambers soon disappears, although the cells at the micropylar end are considerably larger than those at the opposite pole (Figs. 14–16). However, during following stages, the cells at the chalazal end accumulate densely staining protoplasts and begin to multiply at a relatively faster rate than those towards the opposite end (Figs. 16–18), and this activity appears to continue steadily even after cells of more or less uniform size and appearance fill the remainder of the embryo sac (Figs. 18, 19).

During post-fertilization development, the inner integument soon becomes crushed. The outer integument increases in thickness owing to divisions in its cells and in the oldest stage available to me (as in Fig. 19), contains five or six cell layers. Hand in hand with the development of endosperm, a pad of tissue lying between the base of integuments lose their cell contents and the cavities become filled with darkly staining infiltrations (Fig. 19).

SUMMARY.

Decaisnea insignis agrees with *Holboellia latifolia* and *Akebia quinata* in the possession of krassinucellate and bitegumentary ovules and in the formation of a parietal cell which in turn produces three or four layers of similar tissue. As in *Akebia quinata*, Polygonum type of development characterizes the female gametophyte of *Decaisnea*. Organization of a binucleate and secretory type of tapetum, simultaneous method of divisions in the microspore mother cell, development of a single layered endothecium, and two-celled shedding condition of the pollen, are characters shared both by *Akebia* and *Decaisnea*.

The location of the secondary embryo sac nucleus in *Decaisnea* is characteristically nearer to the antipodal cells than to other component cells of the embryo sac, a situation that appears to be paralleled in *Akebia* as can be judged by Vesler's illustrations. In *Decaisnea*, the division of the primary endosperm nucleus is followed by the formation of a wall, thereby halving the embryo sac into a larger micropylar and a smaller chalazal chambers. Both the chambers contribute towards the building up of endosperm. Towards later stages the rate of divisions of endosperm cells situated nearest to the chalazal end appear to become accelerated. Four to six cell layers inclosed by the base of integuments differentiate into an opaque, darkly staining pad of tissue during post-fertilization development.

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I am deeply grateful to the National Institute of Sciences of India, Arnold Arboretum of Harvard University, U.S.A., and to the Madras University for having extended to me opportunities to study this and other problems.

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ON THE RELATION OF *CHLORANTHUS KIANGSIENSIS* TO THE GENUS *CHLORANTHUS*

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When *Chloranthus glaber* (Thunb.) Makino and *C. hainanensis* P'ei are segregated from the other species of the genus, and treated as species of the recently resurrected genus *Sarcandra* Gardner (Swamy and Bailey, 1950), the genus *Chloranthus* (Swartz, 1787) attains homogeneity and compactness. A critical examination of extensive herbarium specimens of all of the nearly 30 species of *Chloranthus* proposed to-date has revealed that approximately half of this number deserve to be reduced to synonymy, thereby finally recognizing 15 or 16 distinct species. The only species that does not fit into the range of variability of the genus is *Chloranthus kiangsiensis* Metcalf (Metcalf, 1942). Arguments to exclude this species from the genus and family are presented in this paper.

The isotype specimen of *Chloranthus kiangsiensis*, S. K. Lau, 4193 (Fig. 1) belonging to the Arnold Arboretum, Harvard University, U.S.A., consists of (1) mounted vegetative part represented by a slender stem with four leaves borne towards the apex, and (2) loose, badly mutilated parts of inflorescence axes and immature fruits preserved in an envelope.

The four leaves, at first sight, appear to be arranged in a whorl, but a careful examination reveals that the phyllotaxy is decussate although the internode between the two pairs of leaves has failed to undergo elongation. The exstipulate leaves are more or less obovate with subacuminate apex, ciliolate-dentate margin, and cuncate base. The petiole is directly attached on to the stem in contrast to the invariable situation in the genus *Chloranthus* (as well as in the other genera of the family) where the petiolar bases fuse to form a vaginate structure sheathing the node and denticular stipules arise from the rim of the vagina. Numerous 'etherial oil cells' are present in the leaves and flowers of *Chloranthus* and of other genera of the family, but *Chloranthus kiangsiensis* typically lacks them. The younger parts of the stem and under-side of the leaves along the veins of the latter species are covered with a dense coating of minute papillae, which, upon microscopic examination, prove to be two-celled epidermal cyst-like outgrowths, their cavities being filled with dark brown contents (Fig. 5). Such a feature is not seen in the Chloranthaceae.

The flowers of *Chloranthus* are bisexual and totally lack a perianth. A somewhat clasping deltoid concave bract directly subtends a styleless pistil with a capitate stigma. The tripartite or trilobed stamen is attached about the middle height of the pistil on its abaxial side. The ovoid fruit is a drupe. The corresponding structures in *Chloranthus kiangsiensis* present a totally different picture:

(1) Although the flowers of this species appear to be hermaphroditic as in the other species of *Chloranthus*, the plan of construction of the flower is at variance. The flower has a conspicuous pedicel arising from the axil of an awl-shaped, membranous bract. The outermost whorl of floral structures consists of five lanceolate appendages with ciliolate margins that are slightly fused at the point of insertion (Figs., 2, 3). This structure has been interpreted by Metcalf as a five-lobed bract.

However, an examination of vascular anatomy of the specimens reveal that apart from the five strands that vascularize the members of the outermost whorl, there are two successive sets of five strands each departing between the outermost whorl and the base of the gynoeceium. The outer set of strands exhibit evidence of trifurcation at their tips while those of the inner set appear to undergo no change. These second and third sets of strands then obviously represent vasculature for corolla and androeceium respectively, both kinds of appendages now fall off. The wall of the gynoeceium is traversed by five strands. This indicates that the flower is constructed on a typically pentamerous plan with a centrally situated gynoeceium surrounded successively by stamen and corolla whorls, and that the outermost whorl should be taken to represent the calyx.

(2) The pistil (in post-fertilization stages) is ovoid with a slender elongate and persistent style that shows a characteristic knob-like swelling slightly above the attachment to the ovary (Fig. 2).

The mature fruit of *Chloranthus kiangsiensis* is ovoid and relatively much smaller than those of the genus *Chloranthus* and shows minute broken striations aligned somewhat longitudinally on the exterior surface (Fig. 4).

The primary xylem of the stem of *Chloranthus*, as also of other genera of the family, is made up of tracheary cells that are unusually long with extensively sloping and overlapping ends with uniseriate scalariform intervacular pitting, and are typically tracheid-like. The corresponding tracheary cells of *Chloranthus kiangsiensis* exhibit a relatively high degree of phylogenetic specialization. This has resulted in the development of short truncate vessel members with transverse-porous ends and multiseriate alternate intervacular pitting.

A critical examination of new and adequate material—particularly of young flowers and fruits—is very essential for an understanding of the affinities of this plant. However, even as it stands, such differences as those narrated above are highly significant for excluding *Chloranthus kiangsiensis* Metcalf not only from the genus, but also from the family Chloranthaceae.

ACKNOWLEDGEMENTS.

I am much obliged to the National Institute of Sciences of India, Arnold Arboretum of Harvard University, U.S.A., and to the Madras University for having extended to me opportunities to carry out this and other investigations.

ABSTRACT

The data obtained through a critical examination of taxonomic and morphological characters of *Chloranthus kiangsiensis* Metcalf warrants the exclusion of this species not only from the genus, but also from the family Chloranthaceae.

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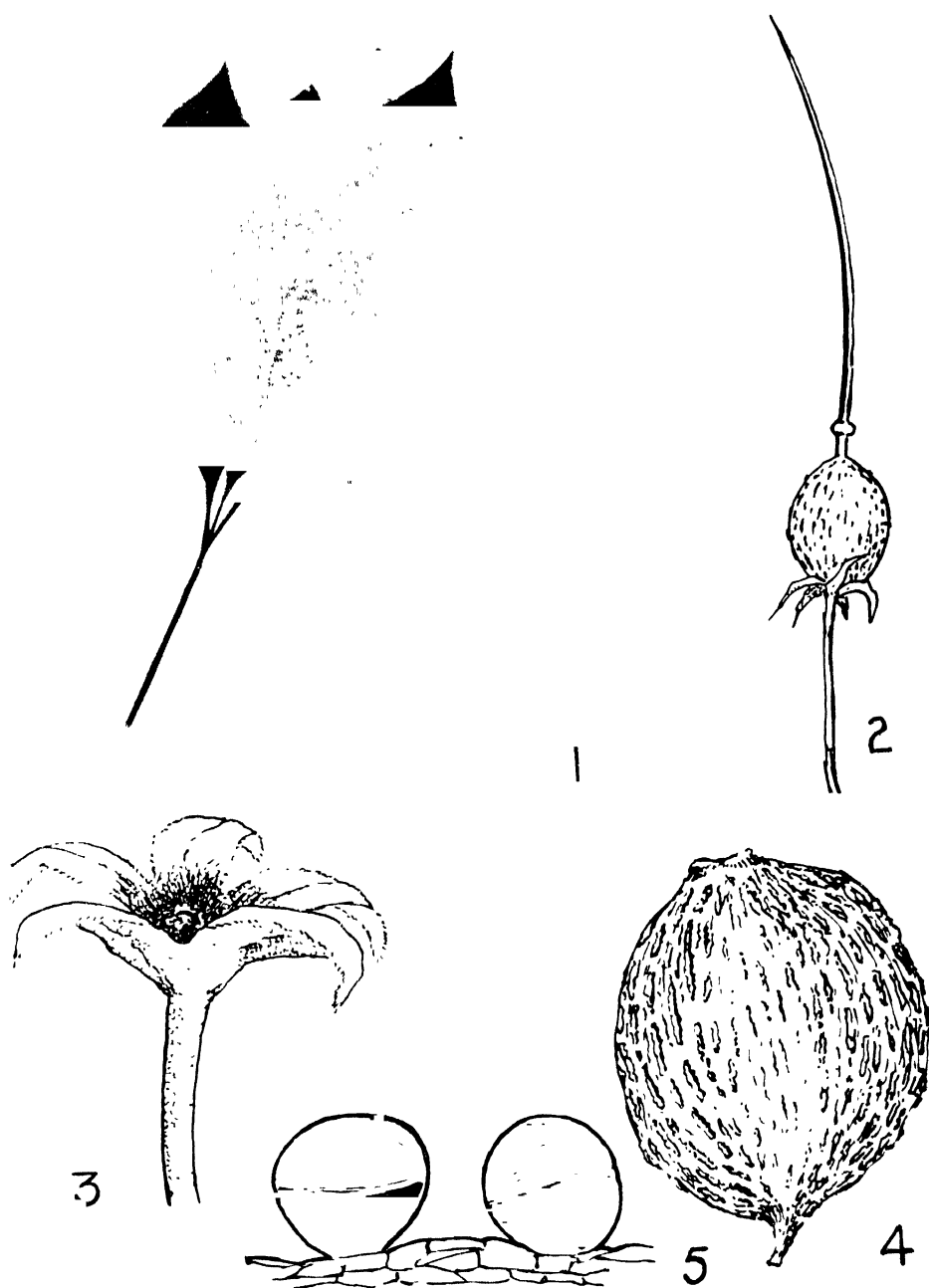


FIG. 1. Photograph of the isotype specimen of *Chloranthus kienziensis* Metcalf (Arnold Arboretum, Harvard University, U.S.A.). FIG. 2. A young developing fruit with persistent calyx. FIG. 3. Calyx whorl, enlarged. FIG. 4. Fairly mature fruit. FIG. 5. Cyst-like outgrowths from the epidermis. 80.

TABLES OF SOLID PARTITIONS

by V. S. NANDA, *University of Delhi, Delhi 8.*

(Communicated by Dr. F. C. Auluck, F.N.I.)

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Asymptotic expressions for the numerical partitions functions $p^{(2)}(n)$ and $p^{(3)}(n)$, which denote the number of plane and solid partitions respectively, were deduced in a recent paper (Nanda, 1951). Recently Gupta (1951) has published his tables for $v^2(n)$ which corresponds to the function $p^{(2)}(n)$ in our notation. Here it is proposed to give tables for $p^{(3)}(n)$, $n \leq 25$.

The generating function for $p^{(3)}(n)$ is

$$\frac{1}{(1-x)(1-x^3)\dots\dots(1-x^r)^{r(r+1)/2}\dots}$$

whence we obtain the recurrence relation

$$n p^{(3)}(n) = \frac{1}{2} \left\{ \sum_{m=1}^n (\sigma^{(3)}(m) + \sigma^{(2)}(m)) p^{(3)}(n-m) \right\} \quad \dots \quad (1)$$

where $\sigma^{(s)}(m)$ denotes the sum of S th powers of the divisors of m . To serve as a check in the results obtained from equation (1) another recurrence relation was employed. For this purpose we break the partitions into classes such that those having the same integer as the smallest summand* are placed in the same class. Denoting by $p^{(3)}(n, m)$ the number of partitions in which the smallest summand is m we notice that these partitions are generated by the function:

$$\frac{1}{(1-x^m)^{m(m+1)/2}\dots\dots(1-x^r)^{r(r+1)/2}\dots}$$

It can be easily shown that

$$p^{(3)}(n, m) = \sum_{r=1}^n (-1)^{r+1} \binom{m(m+1)/2}{r} W^{(3)}(n-rm, m)$$

where

$$W^{(3)}(n, m) = \sum_{t=m}^n p^{(3)}(n, t).$$

We also notice

$$p^{(3)}(n, m) = 0 \text{ for } n > m > \frac{n}{2},$$

and

$$p^{(3)}(n, n) = n(n+1)/2$$

The last relation defines the position of $p^{(3)}(n)$ in the tables for $p^{(3)}(n, m)$.

* The term 'value of the summand' is used here in the usual sense employed in the enumeration of eigen-functions of multi-dimensional oscillator assemblies. MacMahon (1916) in his treatise has used this term in another sense while referring to plane and solid partitions. For a detailed discussion of this double meaning see Nanda (*loc. cit.*), pages 593-94.

ACKNOWLEDGEMENT.

I am thankful to Dr. F. C. Auluck for his interest in the progress of this work.

SUMMARY.

Recurrence relations for solid partitions are deduced. A table of partition is also constructed for values of $n \leq 25$.

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Tables for $p^{(3)}(n, m)$, $m \leq [n/2]$

	13	14	15	16	17	18	19	20	$\leftarrow \frac{n}{m}$ ↓
	13602	27613	55579	1 10445	2 17554	4 24148	8 20294	15 72647	1
	8059	16402	32561	64520	1 25986	2 44448	4 69195	8 95077	2
	3458	6717	13377	25877	49949	95085	1 80254	3 38003	3
	1275	2905	5350	9985	17965	33665	62895	1 17287	4
	540	675	1505	3510	7995	14505	24405	40755	5
	588	756	945	1155	1386	3409	8379	19047	6
		406	1008	1260	1540	1848	2184	2548	7
6	231			666	1620	1980	2376	2808	8
5	420	315	120			1035	2475	2970	9
4	580	280	210	150	55			1540	10
3	1737	861	378	182	90	60	21		
2	3973	1899	916	414	201	81	40	18	
1	6583	3162	1483]	692	310	141	59	26	
$\uparrow \frac{m}{n}$ →	12	11	10	9	8	7	6	5	

	21	22	23	24	25	$\leftarrow \frac{n}{m}$ ↓
	29 92892	56 52954	106 05608	197 65082	366 09945	1
	16 92143	31 79406	59 29721	109 93373	202 50589	2
	6 31124	11 68226	21 51409	39 34674	71 59108	3
	2 14610	3 89805	7 00720	12 59890	22 50405	4
	70455	1 26605	2 32605	4 16700	7 34633	5
	34083	56007	84819	1 34358	2 22334	6
	7000	17976	40726	71974	1 16004	7
	3276	3780	4320	13332	35478	8
	3510	4095	4725	5400	6120	9
	3630	4290	5005	5775	6600	10
2	6	2211	5148	6006	6930	11
1	10	4	1	3081	7098	12
$\uparrow \frac{m}{n}$ →	4	3	2			

NON-CONCYCLIC SETS OF POINTS

by HANSRAJ GUPTA, Hoshiarpur, Punjab.

(Received September 9, 1952; read January 1, 1953.)

1. Sylvester conjectured and Grünwald proved that—

If a finite number of distinct points in a plane are such that a line through any two of them passes through a third then all the points lie on a line.

An analogue of this is—

THEOREM A. *If a finite number of distinct points in a plane are such that a circle through any three of them passes through a fourth then all the points lie on a circle.*

A generalization would be

THEOREM B. *If a finite number of distinct points in space are such that a sphere through any four of them passes through a fifth then all the points lie on a sphere.*

The generalization can be extended to the k -dimensional space also.

The object of this note is to give a proof of Theorem A.

The argument would apply to Sylvester's theorem with slight modifications. Throughout this note we shall confine ourselves to real points in the finite part of an extended real Euclidean plane. The term circle shall include a 'straight circle'.

2. Proof of Theorem A.

Theorem A can be stated in the form:

If a finite number of distinct points in a plane are non-concyclic and a circle is drawn through every three of them then at least one of the circles so obtained contains exactly three of the points.

We shall call such a circle a ' g -circle' with respect to the system of points.

The theorem can be easily verified for sets of 4, 5 and 6 points.

Let us assume that the theorem holds for every set of $(n-1)$ or fewer coplanar points (not less than four, of course). Then we show that it holds when another point distinct from the $(n-1)$ points of the set is added to the set. We label the points $p_1, p_2, p_3, \dots, p_n$ and take $n \geq 7$. By a k -set we shall mean a set of k distinct coplanar points $p_1, p_2, p_3, \dots, p_k$.

Firstly, let the $(n-1)$ points p_1, p_2, \dots, p_{n-1} be concyclic.

Then the point p_n may or may not lie on the circle through the $(n-1)$ points p_1, p_2, \dots, p_{n-1} .

In the former case, the n points are concyclic. In the latter case, every circle through p_n and two of the points p_1, p_2, \dots, p_{n-1} is a g -circle.

Secondly, when the $(n-1)$ points p_1, p_2, \dots, p_{n-1} are not concyclic.

If p_n does not lie on every g -circle of the set of $(n-1)$ points p_1, p_2, \dots, p_{n-1} , then there is nothing to prove; if it does then take one of the g -circles of the $(n-1)$ set containing the points p_1, p_2, p_3 , say.

This passes through p_n by supposition.

If the points $p_4, p_5, p_6, \dots, p_n$ are concyclic and this circle does not pass through any of the points p_1, p_2 or p_3 , then the circles $p_n p_1 p_m, p_n p_2 p_m, p_n p_3 p_m, 4 \leq m \leq n-1$; are g -circles for the n -set. If the circle through $p_4, p_5, p_6, \dots, p_n$ passes also through one of the points p_1, p_2 or p_3 , say p_1 , then the circles $p_n p_2 p_m, p_n p_3 p_m, 4 \leq m \leq n-1$; are g -circles for the n -set.

Finally, suppose that the points $p_4, p_5, p_6, \dots, p_n$ are not concyclic. Consider the sets of non-concyclic points :

- (1) $p_4, p_5, p_6, p_7, \dots, p_n$;
- (2) $p_1, p_4, p_5, p_6, \dots, p_n$;
- (3) $p_2, p_4, p_5, p_6, \dots, p_n$;
- (4) $p_3, p_4, p_5, p_6, \dots, p_n$;
- (5) $p_1, p_2, p_4, p_5, \dots, p_{n-1}$;
- (6) $p_2, p_3, p_4, p_5, \dots, p_{n-1}$;
- (7) $p_3, p_1, p_4, p_5, \dots, p_{n-1}$;

Each of these sets has at least one g -circle pertaining to it. If the g -circle pertaining to set (1) is also a g -circle for each of the sets (2), (3), (4) then there is nothing left to prove. If a g -circle pertaining to set (1) is not a g -circle for one or more of the other sets then the g -circles pertaining to sets (2) to (7) provide at least one g -circle for the n -set. This follows from the fact that no circle can cut the circle through p_1, p_2, p_3 and p_n in more than two of these four points. This proves the theorem.

3. If $g(n)$ denotes the least number of g -circles pertaining to a set of n non-concyclic points, whatever their configuration, then in all probability $g(n) \geq 4$. I am, however, not yet able to prove it.

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 In view of a result in the paper by Dirac, the words 'in a plane' in Theorem A can be omitted.

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STELLAR MODEL WITH LARGE RADIUS

by T. C. ROY, *Ghosh Research Scholar in Applied Mathematics Department,
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INTRODUCTION.

It has been suggested that models of red giant stars can be furnished by a point source stellar model with radiative envelope of nonhomogeneous composition. This nonhomogeneity may conveniently be introduced by a discontinuity in molecular weight somewhere in the envelope in deference to the idea that the outer part of giant stars may be built up by the accretion of interstellar matter. Such non-homogeneity in composition is expected to reproduce the giant characteristic. The red giant model is thus supposed to be built up of a convective core, which is a polytrope 1.5 and an envelope; in this respect it resembles the homogeneous dwarf star model of Cowling, but in the case of the red giant the envelope consists of two parts. The part which is a continuation of the core is supposed to have the same composition as the core itself, while the outer part of the envelope is supposed to have a different composition and for simplicity of analysis it is assumed that these two parts meet on a spherical surface of discontinuity. Such a model was first suggested by Hoyle and Littleton. Opik worked out several such models but his work failed to confirm the expected large radius. In a recent paper Li Hen and Schwarzschild (1949) have worked out several such models in which the discontinuity in composition is taken account of, by variation of Hydrogen and Helium contents, X and Y respectively, in the two parts of the star. They have shown that models exist with such discontinuities, in which for mass equal to $10M_{\odot}$ and luminosity of the order of $10^5 L_{\odot}$, radii ranging from $13R_{\odot}$ to $66R_{\odot}$ may be expected. A feature apparent from their numerical tables of integration is that the larger radii are associated with large discontinuities in the values of X or Y , or of both at the interface. The present work started about two years ago is on the same line. It was stopped for a time and has been recently completed. Here the entire discontinuity in composition is represented by one parameter μ , the molecular weight of the stellar material, and the amount of discontinuity is supposed to be controlled by Hoyle's condition in the form

$$\mu_e(n_e+1) = \mu_i(n_i+1) \quad \dots \quad \dots \quad (1)$$

which is strictly true if we assume

$$(1+X_e)(1-X_e-Y_e) = (1+X_i)(1-X_i-Y_i) \quad \dots \quad (2)$$

The indices e and i signifying external and internal values. Calculations in the present paper show that all these conditions can be satisfied for very small changes of Hydrogen and Helium contents. Or if we represent the opacity law (as has been done here) by

$$K = K_0 \rho T^{-3.5} \quad \dots \quad \dots \quad (3)$$

for constant K_0 , the relations (1) or (2) imply that the same value of K_0 , i.e. the same opacity law is assumed for the whole star. The point of the calculation in

the present paper is that radii 30 to $40R_{\odot}$ and also larger are attained even without assuming large changes in the Hydrogen and Helium contents at the interface.

1. In order to be able to make use of the existing integration results we have used two systems of non-dimensional variables in this paper. They are of course mutually convertible, and the final results have been expressed in terms of one system. Of these two systems, one was used by Cowling, Hoyle, Littleton, and the other by Ledoux, Li Hen and Schwarzschild. We shall call the two systems (A) and (B) respectively. In the following ξ_c is the reduced radius of the core, ξ_s the reduced radius of the surface of discontinuity and ξ_R the total radius of the star.

Equations in system A are :—

$$\frac{d}{d\xi}(\sigma\theta) = -\frac{5}{2} \frac{\sigma\psi}{\xi^2}, \quad \dots \dots \dots \text{(Ia)}$$

$$\frac{d\psi}{d\xi} = \sigma\xi^2, \quad \dots \dots \dots \text{(Ib)}$$

$$\sigma = \theta^{1.5} \quad \dots \dots \dots \text{(Ic)}$$

$$\text{for } 0 < \xi < \xi_c;$$

and

(Ia), (Ib), and

$$\frac{d\theta}{d\xi} = -Q \frac{\sigma^2}{\xi^2 \theta^{6.5}} \quad \dots \dots \dots \text{(IIc)}$$

$$\text{for } \xi_c \leq \xi < \xi_s,$$

Thirdly,

$$\frac{d}{d\xi}(\sigma\theta) = -\frac{5}{2} \frac{\mu_e \sigma\psi}{\mu_i \xi^2} \quad \dots \dots \dots \text{(IIIa)}$$

with (Ib) and (IIc) for $\xi_s \leq \xi < \xi_R$

The variables θ , σ , etc., have their usual significance. The opacity law assumed here $K = K_0 \rho T^{-3.5}$ is that of Kramer, where K_0 is supposed to be constant throughout the star. The dependence of K_0 on the composition finds expression in equation (2).

Equations in system B are—

$$\left. \begin{aligned} \frac{d \log U}{d \log \xi} &= 3 - U - \frac{5}{2} \frac{n}{n+1} V; \quad \frac{d \log (n+1)}{d \log \xi} = U - \frac{5}{2} \left(\frac{6.5 - 2n}{n+1} \right) V; \\ \frac{d \log V}{d \log \xi} &= U + \frac{5}{2} \frac{1}{n+1} V - 1; \quad \text{for } \xi_c \leq \xi < \xi_R. \end{aligned} \right\} \dots \text{(6)}$$

Inside the core, however, the first two of the above equations remain the same, and the third is replaced by the equation $n = 1.5$.

The boundary conditions in system A are :—

at ξ_c , θ , σ , ψ , and $\frac{d\theta}{d\xi}$ are continuous;

at ξ_s , θ , ψ , $\frac{d\theta}{d\xi}$ are continuous; and

$$\frac{\sigma_s}{\sigma_i} = \frac{\mu_s}{\mu_i} \quad \dots \dots \dots \text{(7)}$$

The boundary conditions in system B are :—

at ξ_c , U , V and n are continuous ;

$$\text{at } \xi_s, \quad \frac{U_s}{U_i} = \frac{V_s}{V_i} = \frac{\mu_s}{\mu_i} = \frac{n_i+1}{n_s+1} \quad \dots \quad (8)$$

The first two equations in (8) follow from $\frac{\sigma_s}{\sigma_i} = \frac{\mu_s}{\mu_i}$, while the last equality is really Hoyle's condition together with (2).

2. For convective stability the condition to be satisfied is

$$\left(\frac{d \log P}{d \log T} \right)_{\text{rad}} > \left(\frac{d \log P}{d \log T} \right)_{\text{ad}} \quad \text{i.e. } n \geq 1.5 \quad \dots \quad (9)$$

Obviously then at $\xi = \xi_c$ we should have $\frac{dn}{d\xi} > 0$ in order that a radiative region may exist immediately beyond the core, for with $\frac{dn}{d\xi} < 0$, no radiative region can begin at ξ_c without change of composition. Under this condition to build a model of the type we are seeking, a change of composition should be introduced immediately on the surface of the core, so that the region of the envelope with the same composition as that of the core would now disappear ($\xi_c = \xi_s$).

$$\text{Again} \quad \frac{d \log n}{d \log \theta} = 6.5 - 2n + \frac{d \log \psi}{d \log \theta} \quad \dots \quad (10)$$

Hence making the right-hand side equal to zero we get the maximum value of the core radius for which this intermediate radiative region would cease to exist. Using the values of the quantities on the right-hand side from Emden's table $n = 1.5$, we get $\frac{dn}{d\xi} = 0$, for $\xi_c = 1.4$ approximately.

Opik, by introducing his discontinuities on the surface of the core did not get large radii for his configurations. So in the present work, the intermediate radiative region having the same composition as that of the core has been supposed to exist, and consequently ξ_c has been taken less than 1.4.

3. Several numerical integrations were performed with discontinuities satisfying condition (1) introduced at different distances from the core, but in only three of them approximate constancy of mass could be secured at the stage when the ratio of the discontinuity of the molecular weights $\frac{\mu_s}{\mu_i}$ was correct up to five decimal places. As means for pushing up the calculation to more decimal places for the ratio $\frac{\mu_s}{\mu_i}$ were not at our disposal, the cases where five places of decimal for $\frac{\mu_s}{\mu_i}$ proved to be insufficient were dropped. The three cases completed are shown in the tables given.

It is easily seen that for a core smaller than the Cowling core, the solution according to our assumption (1) would require a smaller molecular density in the core than in the envelope, and so only cores larger than the Cowling core have been considered here. Generally it may be said that for a given such core (with the reduced core-boundary radius $\xi_c < 1.4$, for avoiding a discontinuity at the core

surface which case has already been discussed by Opik) the surface of discontinuity may be introduced arbitrarily within a certain limit. The fixation of the position of the surface of discontinuity also fixes the requisite ratio $\frac{\mu_e}{\mu_i}$ of the model. It has been found that for a given core, as the surface of discontinuity recedes from the core surface, the ratio $\frac{\mu_e}{\mu_i}$ of the model decreases, in other words the amount of necessary discontinuity in the model becomes larger, and the radius (also mass) of the model increases.

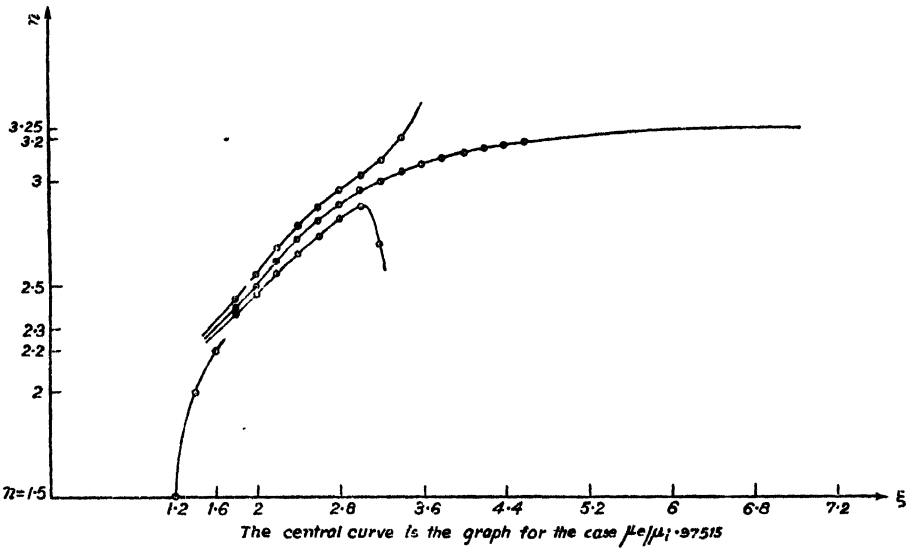


TABLE I.

Table of Numerical results for $M = 10 M_{\odot}$, $T_c = 30 \times 10^6$ and 20×10^6 °K.

μ_e/μ_i	ξ_c	ξ_s	ξ_R	$\log L/L_{\odot}$	T_c in million °K	R_c/R_{\odot}	R_s/R_{\odot}	R/R_{\odot}
.97515	1.2	1.60	7.38	5	30	1.7	2.29	11.4
					20	2.6	3.44	17.2
.89362	1.25	1.55	22.6	5	30	1.8	2.23	32
					20	2.7	3.32	48
.83710	1.25	1.65	31.3	4.9	30	1.8	2.36	42
					20	2.7	3.54	63

4. As has been remarked before, the calculations made by us with condition (1) will be the accurate condition at the surface of discontinuity $\xi = \xi_s$, if condition (2) holds good in addition. To equation (2) we now add the equation

$$\frac{1+3X_s+.5Y_s}{1+3X_i+.5Y_i} = \frac{\mu_s}{\mu_i} \quad \dots \quad (11)$$

Taking the values of $\frac{\mu_s}{\mu_i}$ from our integrations we may obtain from (2) and (11) the compositions of the core and of the outside of the envelope consistent with our solutions when any two of X_s, Y_s, X_i, Y_i are given. Assuming values for X_s and Y_s the same as in some of the models worked out by Li Hen, M. Schwarzschild (page 644) we have calculated X_i and Y_i which will be consistent with the assumed values of X_s and Y_s according to our solutions. The table given below shows that large discontinuities in composition are not always necessary to attain nearly as large radii as obtained for the calculated models of Li Hen and Schwarzschild.

TABLE II.

X_s	Y_s	μ_s	R/R_\odot	X_i	Y_i	μ_i
.39	.00	.92	32 (28)	.304 (.15)	.05 (.00)	1.03 (1.39)
.65	.25	.65	42 (43.2)	.15 (.02)	.44 (.88)	.77 (1.34)

The figures in parenthesis are those of the corresponding models of Li Hen and Schwarzschild.

Even small amounts of discontinuities may produce models with radii of the order of $40R_\odot$. On the whole, the order of largeness of the radius of these models does not appear to be dependent on the condition that the chemical compositions of the stellar material in the core and in the outside envelope should be widely different. Further it would be unsafe to draw any conclusion regarding the chemical compositions of the interior from the mass, radius and luminosities of such models with non-homogeneous compositions.

SUMMARY.

A model of star of non-homogeneous composition is constructed having a convective core and a radiative envelope. It is shown that to get a radius nearly as large as was found by Li Hen and M. Schwarzschild (1940), it is not necessary to have a wide variation in composition as generally happens in the cases considered by them. It is shown that even if quite small variation in the percentage of hydrogen and helium content occurs between the inner and outer regions of the star a stellar radius nearly of the same order of magnitude as in the models of Li Hen and M. Schwarzschild may be expected. In other respects our results generally confirm those of Li Hen and M. Schwarzschild.

ACKNOWLEDGEMENT.

I take this opportunity to express my grateful thanks to Prof. N. R. Sen for his kind help and guidance in the preparation of this paper.

REFERENCE.

Li Hen and Schwarzschild, M. (1949). Red-giant models with chemical inhomogeneities. *M.N.*, 109, 631.

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SKELETON OF CYPRINOID FISHES IN RELATION TO PHYLOGENETIC STUDIES.

5. THE SKULL AND THE GASBLADDER CAPSULE OF THE COBITIDAE

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INTRODUCTION.

Having reported on the skeletal structure and its bearing on the inter-relationship of the Cyprinoid families Gyrinocheilidae (Ramaswami, 1952*a*), Psilorhynchidae (Ramaswami, 1952*b*), Homalopteridae (Ramaswami, 1952*c*) and Gastromyzonidae (Ramaswami, 1952*d*), I am now reporting on the Cobitid skeleton. The Cobitidae, unlike other families studied, show certain distinguishing skeletal characters which are, however, not noticed in any other Cyprinoid family studied so far.

Regan (1911) described the osteological characters of the Cobitidae as follows:

Premaxillae excluding the maxillaries from gape; pharyngeal teeth uniserial, often rather numerous, on the inner and posterior edges of sub-triangular laminar expansions of the pharyngeal bones, which are scarcely falciform; pharyngeal process of basioccipital sometimes very small, sometimes larger and meeting below the aorta, but *never* united and not supporting a horny pad. Subtemporal fossa shallow; a lateral occipital foramen on each side of foramen magnum. Preorbital and suborbital unossified.

He divided the family into two taking into consideration the nature of the mesethmoid.

The two divisions are:

- (1) Mesethmoid firmly united to frontals; skull depressed; anterior part of air-bladder nearly divided into two, the lateral halves of the capsule connected by a narrow bridge; no spine.—Nemachilinae.

Examples: *Nemachilus*, *Diplophysa*, etc.

* Now at Natural History Museum, Stanford University, California.

(2) Mesethmoid movably articulated with frontals; skull compressed. air-bladder undivided.—Cobitidinae.

(a) No spine. *Misgurnus*.

(b) Lateral ethmoid a movable spine. *Botia*, *Acanthopsis*, *Lepidocephalichthys*, *Cobitis*, etc.

Sagemehl (1891) described the skull structure of six genera of Cobitidae, viz., *Misgurnus*, *Nemachilus*, *Cobitis*, *Diplophysa*, *Botia* and *Acanthopthalmus*. In describing the bones of the skull, the nomenclature adopted by Sagemehl is now obsolete. He has figured the skulls of *Cobitis* and *Botia*.

Berg (1940) who followed the descriptions of Chranilov (1927) divided the family Cobitidae into three subfamilies, viz., Cobitini, Botini and Nemachilini. In the Nemachilini the mesethmoid, prevomer and the lateral ethmoid bones are immovably connected with the frontals and orbitosphenoid, and the lateral ethmoid bears no spine; the pharyngeal processes unite below the aorta. In the Botini, the mesethmoid is immovable while the lateral ethmoid is movable and possesses a suborbital spine. In the Cobitini the mesethmoid, prevomer and the lateral ethmoid are movable and the latter bears a spine; the metapterygoid has a large foramen.

I have examined the following species with a view to study the skeletal features of the Cobitidae:

- | | |
|-------------|---|
| Cobitini | .. <i>Cobitis taenia</i> L., <i>C. biwae</i> (Jordan & Synder), <i>Misgurnus angullicaudatus</i> (Cantor), <i>M. fossilis</i> (Linn.); <i>Acanthopsis chaerorhynchus</i> Bleeker, <i>Acanthopthalmus pangia</i> (Ham. Buch.), <i>Lepidocephalichthys guntea</i> (Ham. Buch.), <i>Somileptes gongota</i> (Ham. Buch.). |
| Botini | .. <i>Botia lohachata</i> Chaudhuri, <i>B. hymenophysa</i> Bleeker, <i>B. birdi</i> Chaudhuri. |
| Nemachilini | .. <i>Nemachilus dayi</i> Hora, <i>N. botia</i> (Ham.), <i>N. rupicola</i> (McClelland), <i>N. barbatulus</i> L., <i>N. microps</i> (Steind.), <i>Nemachilichthys rüppelli</i> (Sykes), <i>Diplophysa stewarti</i> Hora, <i>D. papilloso-labiata</i> Kesslr., <i>Adiposia macmohni</i> Chaudhuri. |

Cobitis biwae and *Botia birdi* did not yield good preparations of the skeleton. From the above list, it could be seen that I have examined genera belonging to all the three cobitid subdivisions of Berg.

OBSERVATIONS.

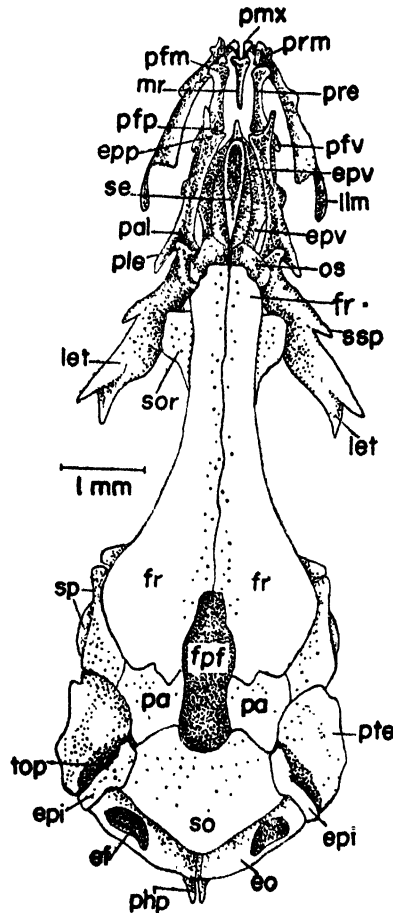
Cobitini.—For the sake of convenience, I shall take up the subfamily Cobitini first and describe the skeletal characters of one important genus and then compare the features of the other genera studied by me.

In the ethmoid region of *Cobitis*,—the family and subfamily being named after this genus, the supraethmoid portion is slightly broad and the ethmoid portion forms a vertical septum separating the two olfactory sacs. In the anterior end of the supraethmoid portion, there is a slight depression.

Ventrally the prevomer is united with the ethmoid to form a composite bone,—the ethmoprevomer, a unique feature noticed among the Cyprinoidea. From this united bone, anteriorly there are apophyses looking more like prevomerine projections with which the preethmoid articulates by a process (Text-fig. 1, *pfv*). The preethmoid (*pre*) is a three-pronged bone, situated on either side in front of the united ethmoprevomer (*epv*). It articulates anteriorly by a facet (*pfm*) with a similar facet (*prm*) on the maxilla; posteriorly it has two facets. The flat dorsal

one (*pfp*) articulates with the elongated ethmoid process (*epp*) of the palatine (*pal*) while the ventral one (*pfv*) articulates with a round prevomerine facet.

The premaxilla (Text-fig. 1, *pmx*) shows a large rostral process and a lateral limb. The maxilla exhibits a prominent anterior premaxillary process, a posterior facet for articulating with the preethmoid, a ventral rostral process and a process from the broad lateral limb for the insertion of the ligament of the adductor mandibulae muscles.



TEXT-FIG. 1. Dorsal aspect of the skull of *Cobitis taenia* Linn.
(The sensory canal ossicles are omitted.)

The lateral ethmoid¹ (Text-fig. 1, *let*) is a well developed elongated bone with quite a few processes: one of these processes (*ssp*) is usually described as the sub-orbital spine. Mesially the bone articulates by means of a prominent head with the orbitosphenoid.

The lacrimojugal (not drawn in Text-fig. 1) is a flat strip of bone in front of the lateral ethmoid. As there is no anterolateral process from the lateral ethmoid, the lacrimojugal does not come in contact with it. There are a number of sensory

¹ Prefrontale (ectethmoid), according to Chranilov (1927a).

canal ossicles lying laterally to the lacrimojugal forming a part of the suborbital series.

The median rostral (Text-fig. 1, *mr*) is an obliquely vertical bone whose dorsal end is enlarged to receive the two rostral processes of the premaxilla.

I shall consider the palatine here though it belongs to the upper jaw. The edentulous palatine (Text-fig. 1, *pal*) while articulating at its middle with the ethmoprevomer, shows anteriorly a prominent process (*epp*) with which a prominent process (*ppf*) of the preethmoid (*pre*)¹ comes in contact. Laterally to this articulation, the palatine has a prominent pointed process.

The orbitotemporal region: In *Cobitis*, there is a large supraorbital bone (Text-fig. 1, *so*)². The large frontals and the small parietals bound anteriorly and laterally the fronto-parietal fontanel (*ppf*). Each frontal laterally shows a ventral shelflike extension. Peculiarly the frontals do not disclose laterally the passage of the supraorbital sensory canal; however, the canal passes through independent ossicles on the frontal and anteriorly, there is a very small nasal bone.

A reference to the orbitosphenoid has already been made; it is noticed on either side of the ethmoprevomer (Text-fig. 1, *os*) dorsally in front of the frontals. Ventrally the united orbitosphenoid is noticed just posterior to the ethmoprevomer mesially to the anterior articulations of the lateral ethmoid. The orbitosphenoid extends below the frontals as two posterior limbs and ventrally, above the parasphenoid, there is a median posterior limb of the same. Since the orbitosphenoid is limited to the anterior end of the orbitotemporal region, the orbit is very large and there is usually a membranous interorbital septum. The pleurosphenoid³ is a small ossification relegated to the posterior wall of the orbit, mesially to the large sphenotic. The parasphenoid does not show any peculiarity.

The infraorbital sensory canal is composed of a series of independent ossicles, ending anteriorly as a large rostral in *Cobitis*.

The auditory region: The sphenotic⁴ (Text-fig. 1, *sp*) and pterotic (*pte*) form the lateral ossifications and posterolaterally there is a small epiotic (*epi*) bone. In the anteromesial region of the pterotic, there is a depression in the bone and this is the temporal opening.* It should, however, be noted that not in all the *Cobitini* examples is this temporal opening noticed. The occipital bones are well developed. The two exoccipitals bound the foramen magnum dorsally and in each, there is a large lateral fenestra. The basioccipital shows two prominent pharyngeal processes (*php*) disunited below the aorta.

I shall give a description of the jaws and hyobranchial skeleton under *Acanthophtalmus* as there is not much difference noticed among the members of *Cobitini*.

The skull of *C. biwae* resembles that of *C. taenia* closely and a separate description of it is therefore, unnecessary.

I shall now describe the skull of *Acanthophtalmus* which shows quite a few differences from that of *Cobitis*.

In the ethmoid region of *Acanthophtalmus* (Text-fig. 2a), a supraethmoid portion is absent and the ethmoprevomer forms a vertical septum separating the olfactory sacs.

Ventrally the united ethmoprevomer (Text-fig. 2a, *epv*) is noticed, from whose anterior end, there are prevomerine projections (*ppv*) with which the preethmoids articulate. The preethmoid also articulates by a facet (*ppf*) with a similar facet (*epp*) of the palatine.

The maxilla exhibits an anterior premaxillary (Text-fig. 2a, *apm*); a pre-ethmoid (*prm*), a ventral rostral (*rpm*) and a lateral ligamentary (*plm*) processes.

The lateral ethmoid of *Acanthophtalmus* resembles that of *Cobitis*.

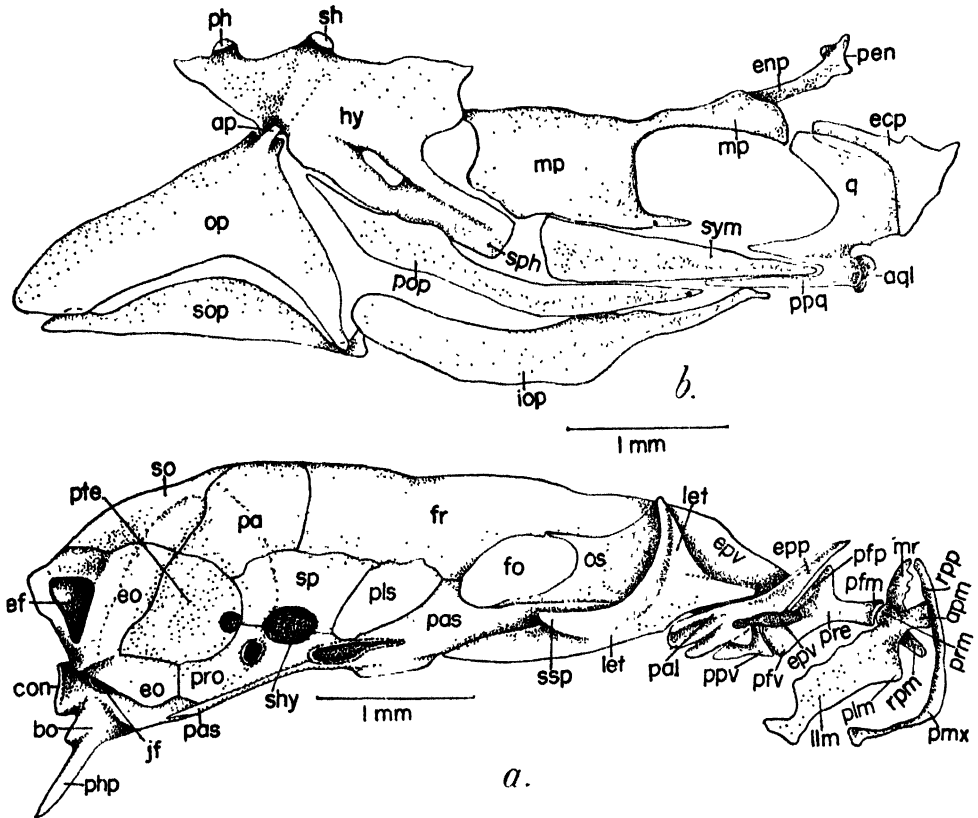
¹ Submaxillare, ² orbitale, ³ alisphenoid, ⁴ postfrontale, according to Chranilov (1927a).

* Chranilov (1927a) does not show a temporal opening in his figure (6, above) of *C. taenia*.

In the orbitotemporal region, there is a bowlike supraorbital bone in *Acanthophtalmus*.

In the auditory region, there is a frontoparietal fontanel. Peculiarly in *Acanthophtalmus*, the frontal instead of merely extending laterally, arches downwards to form a sutural contact with the parasphenoid (Text-fig. 2a, *pas*), pleurosphenoid (*pls*) and sphenotic (*sp*) so that the skull is rounded in this region.

The orbitosphenoid is single and the small pleurosphenoid (Text-fig. 2a, *pls*) is posteriorly situated showing no contact with the orbitosphenoid; in *Acanthophtalmus*, the extensions of the frontal (*fr*) and parasphenoid (*pas*) meet in front of the pleurosphenoid (*pls*) and exclude the latter from the orbit. Thus in this



TEXT-FIG. 2. (a) The lateral aspect of the skull of *Acanthophtalmus pangia* (Harn. Buch.). (b) The upper jaw of *Acanthopsis chaerorhynchus* Bleeker. (Palatine omitted).

example, there is a large optic fenestra roofed by the frontal and floored by the parasphenoid and by the posterior spinous extension of the orbitosphenoid dorsally to the parasphenoid. Into the membranous interorbital septum dorsally, there is also a short projection of the orbitosphenoid.

The auditory region: In *Acanthophtalmus* (Text-fig. 2a), the skull is perfectly rounded in the auditory region, as in the orbitotemporal, without any gaps or temporal fossae and the extension of the frontal (*fr*) coming in contact with the parasphenoid (*pas*) one, as already said, keeps the small lateral pleurosphenoid (*pls*) away from the orbit. Moreover, there is no epiotic bone and the exoccipital (*eo*) is very large showing a large fenestra (*ef*). Probably, the epiotic has united

with the exoccipital. The supraoccipital (*so*) is large and does not show any membranous processes and the two exoccipitals bound the foramen magnum dorsally, keeping out the supraoccipital from forming the roof in this region. The basioccipital (*bo*) gives rise to the pharyngeal processes (*php*) which do not unite below the aorta.

In the upper jaw of *Acanthophthalmus* and *Acanthopsis* (Text-fig. 2b), the metapterygoid (*mp*) is arched in front with a deep indentation towards the quadrate (*q*) and the quadrate also shows a similar indentation towards the metapterygoid. The preopercle (*pop*) is fairly long and does not carry a sensory canal in it. The hyomandibula (*hy*) has a rectangular orifice in it and shows a long symplectic process (*sph*). The symplectic (*sy*) itself is a long wedge-shaped bone. The operculum (*op*) shows an articular process (*ap*) and the lower edge is indented. The entopterygoid (*enp*) is rod like and has a facet for the articulation of the palatine.

In the lower jaw of *Acanthophthalmus*, the dentary and angular are practically of the same size articulating with each other loosely. *Cobitis* also shows a similar condition. The dentary shows a prominent dorsal process. The retroarticular occupies the ventral portion below the angular near the articulation with the quadrate. Mesially there is a canal between Meckel's cartilage and the investing angular which is probably a sensory canal. No other canal is noticed leading the sensory canal in the angular or dentary. At any rate in my previous papers, I have labelled such a mesial canal as a sensory canal. A scsamosid angular is peculiarly absent.

In the hyobranchial apparatus of *Acanthophthalmus*, there are four copulae, two pairs of hypohyals and the basihyal is rodlike with the anterior end slightly enlarged.

The other genera, viz., *Lepidocephalichthys*, *Acanthopsis*, *Somileptes* and *Misgurnus* are similar to *Cobitis* and *Acanthophthalmus* in many features. A supraethmoid is absent in *Acanthopsis* and *Lepidocephalichthys* while in *Somileptes* and *Misgurnus*, there is a slight enlargement as in *Cobitis*. The premaxilla and maxilla of *Lepidocephalichthys*, *Acanthopsis*, *Somileptes* and *Misgurnus* resemble those of *Acanthophthalmus* and *Cobitis* but in *Somileptes*, there is a large lateral process from the maxilla extending laterally to the preethmoid in addition to the other processes.

In the auditory region, the sphenotic, pterotic and epiotic bones are arranged in a line one behind the other; in *Misgurnus* the epiotic also shows a small membranous portion. The supraoccipital in *Misgurnus* and *Lepidocephalichthys* does not show any projecting processes, while in *Somileptes* they are present. The two pharyngeal processes of the basioccipital are large in *Misgurnus* and the similar processes of *Somileptes* are fenestrated; they do not unite ventrally to enclose the dorsal aorta. The subtemporal fossa in *Lepidocephalichthys* and *Misgurnus* is insignificant while it is quite distinct in *Somileptes*. A temporal opening is absent in *Lepidocephalichthys*, *Acanthopsis*, *Somileptes* and *Misgurnus*.*

The upper jaw of *Lepidocephalichthys*, *Acanthophthalmus* and *Somileptes* resembles that of *Acanthopsis* in all important characters. There are a number of small and large orifices in the metapterygoid of *Somileptes*. The hyomandibula of *Somileptes* shows a prominent spine laterally at its middle. The entopterygoid is rodlike and possesses a facet for the palatine.

The lower jaw is the same in all the genera; a glance at figure 4a of the lower jaw of *Somileptes* shows the similarities in structure with that of *Acanthophthalmus*.

The nature of the gasbladder of the Cobitini is very well seen in that of *Somileptes* (Text-fig. 7a). The pleural ribs of the second (*pl2*) and the dorsal (*dr4*, *pr4*) and pleural ribs (*oss*) of the fourth vertebrae contribute towards the

* Chranilov (1927a) also does not show in his figure (6, below) *M. fossilis* a temporal opening.

formation of the single capsule with its lateral openings; however, the dorsal ribs of the second vertebra (*dr2*) are free. There is a posterior opening (*po*) in the capsule for establishing a connection between the anterior and posterior portions of the gasbladder. Of the first vertebra, the projecting centrum (*cl*) and its dorsal ribs are seen; of the second vertebra, the neural arch (*na2*), the dorsal (*dr2*) and pleural (*pl2*) ribs with prominent ventral processes from the latter (*pr2*) are noticed. The neural spines of the second and third vertebrae appear to have fused into a single one (*ns23*). Of the fourth vertebra, the neural arch (*na4*), the neural spine (*ns4*) and the dorsal (*dr4*) and pleural ribs (*oss*) are seen. Of the weberian ossicles, the tripus needs special mention. It has retained its triangular shape resembling very much that in the Cyprinidae.

Botini.—I shall now describe the skull of *Botia*, the only genus that I have studied under *Botini*.

In the ethmoid region, the supraethmoid part (Text-fig. 3*a*, *se*) is slightly broadened out with a deep gully in it. The supraethmoid projects in the form of a short process (Text-figs. 3*a*, 3*b*, *p*) in between the ethmoprevomerine projections. The ethmoprevomer (*epv*) is firmly articulated with the orbitosphenoid and the bone does not come in contact with the anterior end of the frontals (*fr*).

The prepalatine (Text-figs. 3*a*, 3*b*, *ppa*) and the first preethmoid (*pre*) are elongated rodlike bones articulating anteriorly with independent facets (*ppm*, *prm*) of the maxilla. Peculiarly, there is a large oval bone (*sb*), probably a sesamoid, sitting on the articular region of the maxilla and the preethmoid. As I am unable to discover the exact homology of it, I have simply called it an 'oval' bone.

The premaxillae are peculiar in *Botia*. The rostral process (Text-figs. 3*a*, 3*b*, *rpp*) of the premaxilla (*pmx*) takes its origin not at the anterior end as in other examples of Cobitidae, but at the middle of the bone so much so, there is a semi-circular arch of the premaxilla formed in front for supporting the tuft of maxillary barbels.

The maxilla of *Botia* shows all the characteristic processes: the rostral (Text-figs. 3*a*, 3*b*, *rpm*), the dorsal (*dpm*), the preethmoid (*prm*), the prepalatine (*ppm*) process and the process (*plm*) for the attachment of a ligament. The lateral limb (*llm*) is very short.

The lateral ethmoid (Text-figs. 3*a*, 3*b*, *let*) is well developed and shows at least five processes: mesially, it comes in contact with the large orbitosphenoid (*os*). Anteriorly, there is a process and from the lateral aspect of this, there is a small process (*llj*) articulating with the lacrimojugal (*lj*). A prominent suborbital spine (*ssp*) is seen and the posterior spinous process articulates with the lateral edge of the frontal (*fr*).

The lacrimojugal¹ (Text-figs. 3*a*, 3*b*, *lj*) is a thin piece of bone with the posterior end of which, the lacrimojugal process (*llj*) articulates; the rostral (*ros*) is free anteriorly and behind the rostral, there are ten suborbital canal ossicles (*sc3*, *sc9*, *sc10*).

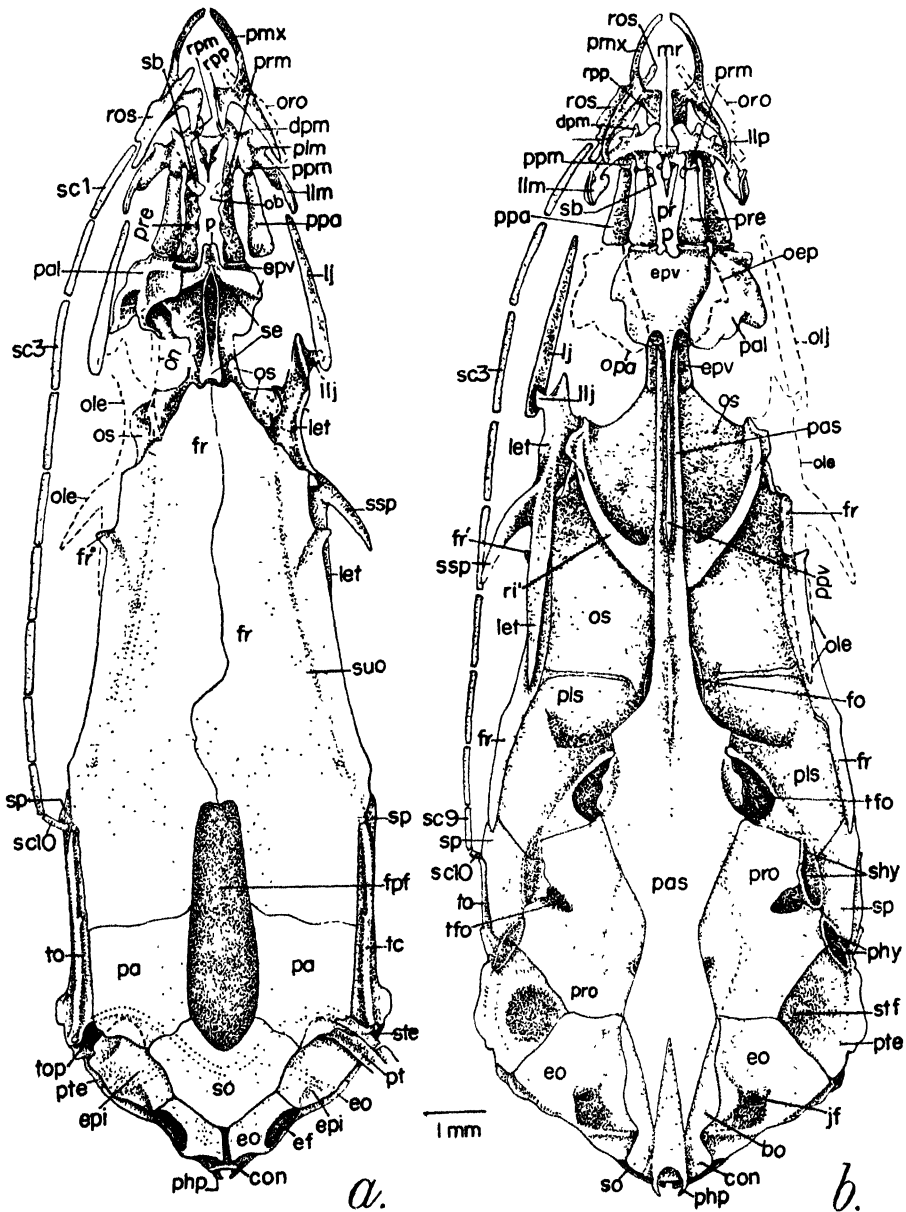
In *Botini*, the median rostral (Text-figs. 3*a*, 3*b*, *mr*) is an obliquely vertical bone whose dorsal end is enlarged; at the middle there are two projections (*pr*), one on either side for the attachment of a ligament. The ventral end is pointed.

The palatine (Text-figs. 3*a*, 3*b*, *pal*) while mesially articulating with the ethmoprevomer, shows anteriorly a prominent facet for the prepalatine (*ppa*). Posteriorly the entopterygoid articulates with a palatine facet.

In the orbitotemporal region, the frontals (Text-fig. 3*a*, *fr*) are large covering bones; each frontal shows a lateral spinous projection (*fr'*), a short distance from its anterior end. Also the passage of a lateral sensory canal is noticed in each bone. The orbitosphenoid (*os*) projects in front as far as the ethmoprevomer so that there is a small gap between the supraethmoid and the frontals. The bone

¹ Preorbitale (Chranilov 1927*a*).

also gives articulation to the lateral ethmoid (Text-fig. 3b, *os*) and ventrally, the large size of the bone could be easily made out; it also shows a large ridge (*ri'*). Posteriorly, it comes in contact with the pleurosphenoid (*pls*) which is also fairly



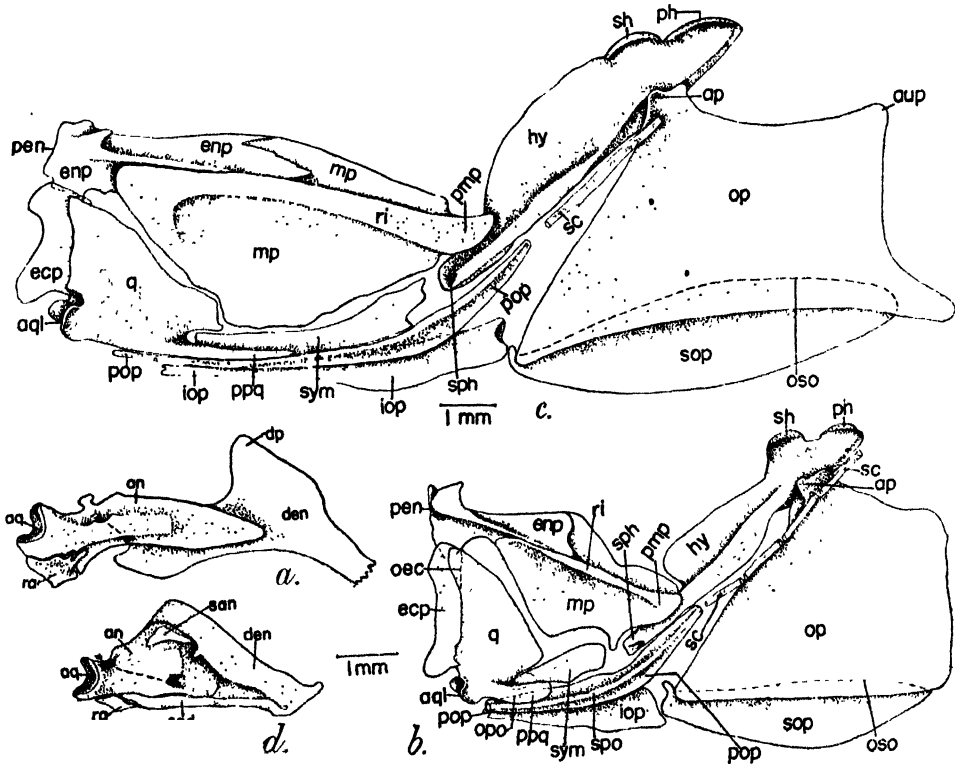
TEXT-FIG. 3. The skull of *Botia hymenophysa* Bleeker.
(a) Dorsal aspect. (b) Ventral aspect.

large. The optic foramen (*fo*) is quite small. A part of the orbitosphenoid anteriorly or in front of the optic foramen dorsally to the parasphenoid (*pas*) forms the interorbital septum, which however, is not visible in the ventral view.

There are two sclerotic bones in the bulbus oculi.

In the auditory region, *Botia* exhibits certain peculiarities. The sphenotic (Text-fig. 3b, *sp*) and pterotic (*pte*) are fairly large ossifications and ventrally, the sphenotic (*sp*), the prootic (*pro*) and the pleurosphenoid (*pls*) contribute towards the formation of the anterior facet (*shy*) for the articulation of the hyomandibula. Between the mesial part of the epiotic (Text-fig. 3a, *epi*), lateral pterotic (*pte*) and the anterior temporal ossicle (*to*), there is a small temporal opening (*top*) for the attachment of a few muscles. The occurrence of a single temporal sensory canal ossicle (*tc*) in front of the supratemporal (*ste*) one in *Botia* is noteworthy.

In the upper jaw of *Botia*, the hyomandibula (Text-figs. 4b, 4c, *hy*) shows a fairly large symplectic process (*shy*) with a short (Text-fig. 4b) or long (Text-fig. 4c)



TEXT-FIG. 4. The skull of Cobitid Fishes (continued).

- (a) Mesial view of the left ramus of lower jaw of *Somileptos gongota* (Ham. Buch.).
- (b) The upper jaw of *Botia lohachata* Chaudhuri. (Palatine omitted).
- (c) The upper jaw of *Botia hymenophysa* Bleeker. (Palatine omitted).
- (d) Mesial view of the left ramus of lower jaw of *Botia hymenophysa* Bleeker.

symplectic (*sym*) in front. The metapterygoid (*mp*) does not show an indentation towards the quadrate (*q*) and along with the entopterygoid (*enp*), they disclose a prominent ridge (*ri*). The metapterygoid (*mp*) comes in contact with the hyomandibula by a short posterior process (*pmp*) which, however, is laterally disposed to the symplectic process of the hyomandibula. The preopercular (*pop*) is slender and long and carries a sensory canal (*spo*) in it which is connected with the temporal canal by a series (*sc*, *B. lohachata*) or a single (*B. hymenophysa*) canal ossicle. The opercle (*op*) is large with its lower border entire and dorsally shows an articular (*ap*) and an auricular process (*aup*).

The lower jaw of *Botia* (Text-fig. 4d) is compactly built. The angular¹ and dentary show ventrally the united sensory canal (*scd*) and mesially also one (indicated by the arrow). The sesamoid angular (*san*) is a fairly large bone.

In the hyobranchial apparatus of *Botia*, the number of copulae is reduced to two and there are present three pairs of hypobranchs and two pairs of pharyngobranchs. Between the two pairs of hypohyals, there is intercalated a piece on which the hypohyals can rotate. This middle piece has its upper and lower surfaces enlarged into button-shaped prominences. I do not know if this is a part of the basihyal; the basihyal proper is feebly expanded anteriorly.

In the two species of *Botia* examined by me, the gasbladder capsule is a pearshaped bony chamber. The dorsal ribs (Text-fig. 7b, *dr2*) of the second vertebra are disposed anteriorly to the apertura magna (*ape*) or the lateral openings and do not take part in the formation of the capsule while the extensions of the pleural ribs (*pl2*) form ridges on the anterior wall of the capsule. The dorsal ribs (*dr4*) of the fourth vertebra form the dorsal boundary of the lateral openings and also extend laterally as projections over the capsule and end as spines (*pr4*). The gasbladder capsule (*gbc*) itself is formed by the pleural ribs (*oss*) of the fourth vertebra and the capsule does not show a posterior opening as in *Somileptes* for connecting the posterior portion of the gasbladder. The first centrum (*c1*) shows a pair of short dorsal ribs (*dr1*); the second vertebra also exhibits the dorsal (*dr2*) and pleural ribs (*pl2*), a neural arch and a short neural spine (*ns2*). The neural arch (*na3*) and neural spine (*ns3*) of the third vertebra are comparatively larger. The fourth vertebra discloses a neural arch and neural spine (*ns4*) and the dorsal (*dr4*) and pleural ribs (*oss*).

With regard to the weberian ossicles, the four ossicles are typically noticed and the tripus is triangular without a transformer process.

Nemachilini.—I shall now describe the skull and gasbladder capsule of *Nemachilus* as an example under the *Nemachilini*.

In *Nemachilus* (Text-figs. 5, 6a), the supraethmoid (*se*) is represented by a slight enlargement of the septum and this posteriorly, comes firmly in contact with the frontals (*fr*); in *N. barbatulus* (Text-fig. 6a), at the region of sutural contact with the frontals (*fr*), the supraethmoid (*se*) is broad. The anterior portion of the supraethmoid projects as a short blunt or long (Text-fig. 6a) process (*p*). In *N. dayi*, *botia* and *rupicola* there is a slight depression in the anterior supraethmoid portion; in *N. microps* and *barbatula* such a depression is absent and the anterior region shows slight enlargement in the former species.

As in the two previous subfamilies, the ethmoid and prevomer have united together to form a composite ethmoprevomer in *Nemachilus* (Text-figs. 5, 6a, 6b, *epv*); the posterior portion of the prevomer (*ppv*) is long in all the nemachiline genera studied. From this ethmoprevomer in *N. dayi* (Text-fig. 5) and *rupicola*, anteriorly there are two apophyses-like prevomerine projections with which the preethmoids (*pre*) articulate. In *N. microps* and *botia*, a second preethmoid is developed with which the rodlike first preethmoid articulates.

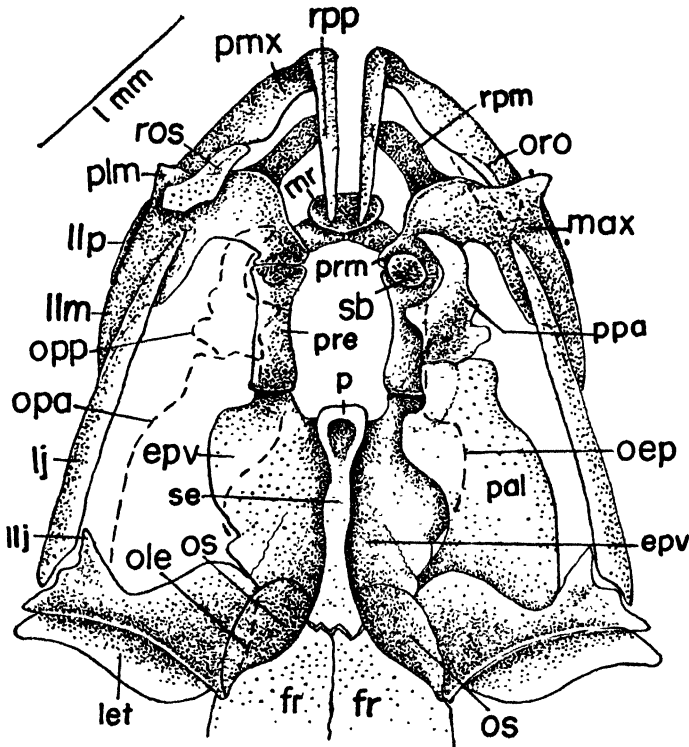
Nemachilus (Text-figs. 5, 6a, 6b) shows a rodlike first preethmoid (*pre*); the prepalatine shows difference in shape in the several species of *Nemachilus*. In *N. dayi* the prepalatine (Text-fig. 5, *ppa*) is sickle-shaped and there is no special facet for articulation with the maxilla in this species; so also in *rupicola*. In *N. microps* and *botia* the prepalatine articulates with the maxilla by a facet. Sitting on the first preethmoid in *N. dayi*, there is a rounded sesamoid bone (Text-fig. 5, *sb*).

The premaxillae of *Nemachilus* (Text-figs. 5, 6a, *pmx*) show a large rostral process (*rpp*) coming in contact with the rostral (*mr*), and a lateral limb (*lm*).

¹ Articulare (Chraniiov, 1927a).

The maxillae of *Nemachilus* (Text-figs. 5, 6a, *max*) show the usual processes, viz., the anterior rostral process (*rpm*), a prominent facet (*prm*) for articulation with preethmoid and a process (*plm*) for the attachment of a ligament. There is no special facet of the maxilla for articulation of the prepalatine (*ppa*) in *N. dayi* but in *microps* and *botia*, it is present. The lateral limb in *N. dayi* (Text-fig. 5, *llm*) is fairly long.

In *Nemachilus*, the lateral ethmoid shows variation: in forms like *N. dayi* (Text-fig. 5, *let*), *rupicola* and *barbatulus* (Text-fig. 6a, *let*), it is a small ossification in the lamina orbitonasalis. In *N. microps*, which is a larger animal, the bone is also comparatively larger. Laterally the bone shows a lacrimojugal process (Text-figs. 5, 6a, *llj*). Ventromesially the bone articulates with the unpaired orbitosphenoid (Text-fig. 6b, *os*). In *N. botia*, the lateral ethmoid and the broad



TEXT-FIG. 5. Dorsal aspect of the ethmoid region of the skull of *Nemachilus dayi* Hora.

lacrimojugal are in close contact and a lacrimojugal process of the lateral ethmoid is thus absent.

The lacrimojugal (Text-fig. 5, *lj*) is a thin strip of bone in front of the lacrimojugal process of the lateral ethmoid in *N. dayi* and *rupicola*; in *microps* there is a broad posterior portion and in continuation with this one anteriorly, there is a small projecting portion. In *N. barbatulus* (Text-fig. 6a) the lacrimojugal and rostral are united into a single ossification (*ljr*). In *N. botia* the lacrimojugal is broad and projects in front of the lateral limb of the lateral ethmoid.

In *Nemachilus* the median rostral (Text-figs. 5, 6a, *mr*) is disposed as in the two previous subfamilies; in the middle of the bone there are two lateral projections for the insertion of ligaments.

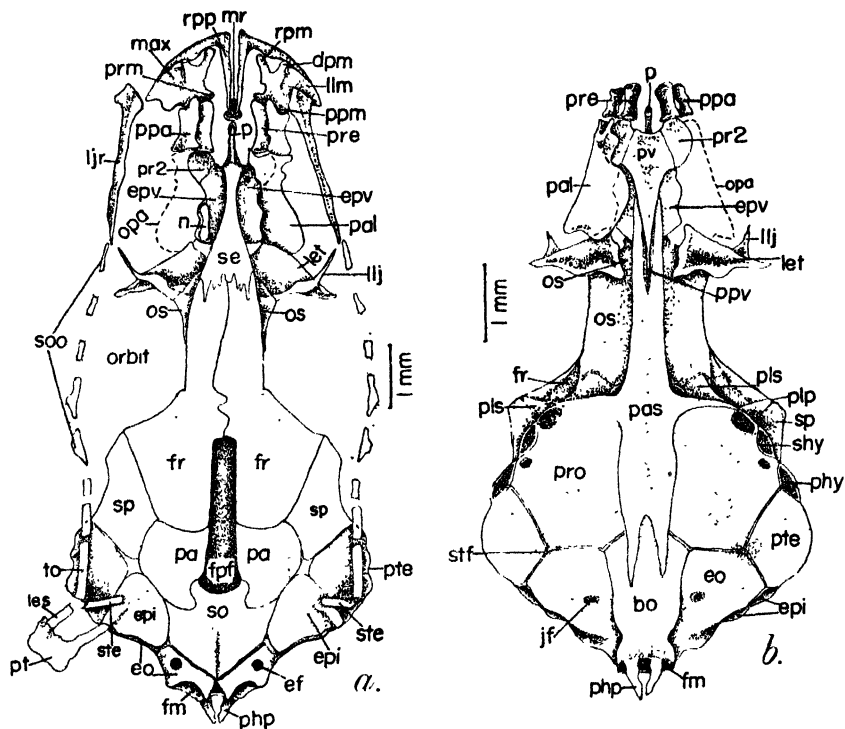
The palatine of *Nemachilus* resembles very much that of *Botia*. It possesses a facet (Text-figs. 6a, 6b, *pal*) for articulation with the prepalatine (*ppa*) and mesially articulates with the large ethmoprevomer and has posteriorly a facet for the entopterygoid.

In the orbitotemporal region, a supraorbital bone is absent in *Nemachilus*.

The frontals (Text-fig. 6a, *fr*) are large bones and between them, the parietals (*pa*) and the supraoccipital (*so*), there is a large frontoparietal fontanel (*fpr*). In the frontals, the passage of the supraorbital sensory canal is not noticed.

The supraorbital sensory canal ossicles are independent of the frontals and end anteriorly as the nasal ossicle in the olfactory region.

Ventrally, the large orbitosphenoid (Text-fig. 6b, *os*) extends posteriorly and meets the large pleurosphenoid (*pls*), the optic foramen (*fo*) being very small. In



TEXT-FIG. 6. The skull of *Nemachilus barbatulus* Linn.
(a) Dorsal aspect. (b) Ventral aspect.

Nemachilus the orbitosphenoid has winglike extensions on either side of the ethmoprevomer in front of the frontals, and the lateral ethmoid comes mesially in contact with them.

The parasphenoid (Text-fig. 6b, *pas*) shows a narrow portion anteriorly and a broad portion in the auditory region of *Nemachilus*. A lateral limb from the posterior portion of it delimits the trigeminofacial opening.

In each eye, there are two cupshaped sclerotic bones.

The auditory region of *Nemachilus* shows some interesting features. In *N. barbatulus* (Text-fig. 6b, *sp*) the sphenotic shows a winglike process and a similar process from the pleurosphenoid comes in contact with it. In other species of *Nemachilus*, the pleurosphenoid projection is absent. The epiotic (Text-fig. 6b,

epi) is posteromesial and the supraoccipital (*so*) does not show any posterior process. The exoccipitals are small and the lateral fenestrae are hardly visible in *N. dayi*, while in other species of *Nemachilus*, they are clearly seen. The basioccipital (Text-fig. 6b, *bo*) shows the pharyngeal processes which have united below the aorta.

There is one peculiarity noticed in the dorsal sphenotic-pterotic region of *Nemachilini*, i.e., the presence of a temporal opening developed on account of the nonextension of the parietal laterally and of the pterotic mesially to meet the parietal. Laterally to this cavity, the independent temporal sensory canal ossicles are noticed on the pterotic bone; the floor of the cavity is formed mostly by the pterotic posteriorly, in front by the sphenotic and mesially by the sphenotic and pterotic; there is, however, a slight extension of the parietal as roof. The mesial limb of the supratemporal and posttemporal lie over the temporal opening so that the muscles from this temporal cavity pass below these bones.

On the ventral aspect of *Nemachilus* (Text-fig. 6b), the pterotic-prootic-exoccipital junction discloses a clearly demarcated shallow subtemporal fossa.

In the upper jaw of *Nemachilus* (Text-fig. 7c), the hyomandibula (*hy*) is broad and the symplectic process (*syh*) is comparatively short; there is a prominent process (*pho*) of the hyomandibula towards the operculum (*op*) in *N. dayi*. The metapterygoid (*mp*) and entopterygoid (*exp*) are broad and the former shows a ridge (*ri'*) on it. The metapterygoid also shows a short posterior process (*opm*) towards the hyomandibula in all the species of *Nemachilus* examined by me. The opercle (*op*) shows only an articular process (*ap*). The preopercle (*pop*) does not show a sensory canal in it except in *N. botia*. However, sensory canal ossicles are noticed by the side of the preopercle.

In the lower jaw, *Nemachilus* shows the usual four bones, viz., the angular, the dentary, the retroarticular and the sesamoid angular. A mesial sensory canal is also noticed.

In the hyobranchial apparatus of *Nemachilus*, there are three copulae, three pairs of hypobranchs and two pairs of pharyngobranchs. Between the two pairs of hypohyals, there is a bony piece intercalated. The basibranchial is anteriorly forked assuming a Y-shape.

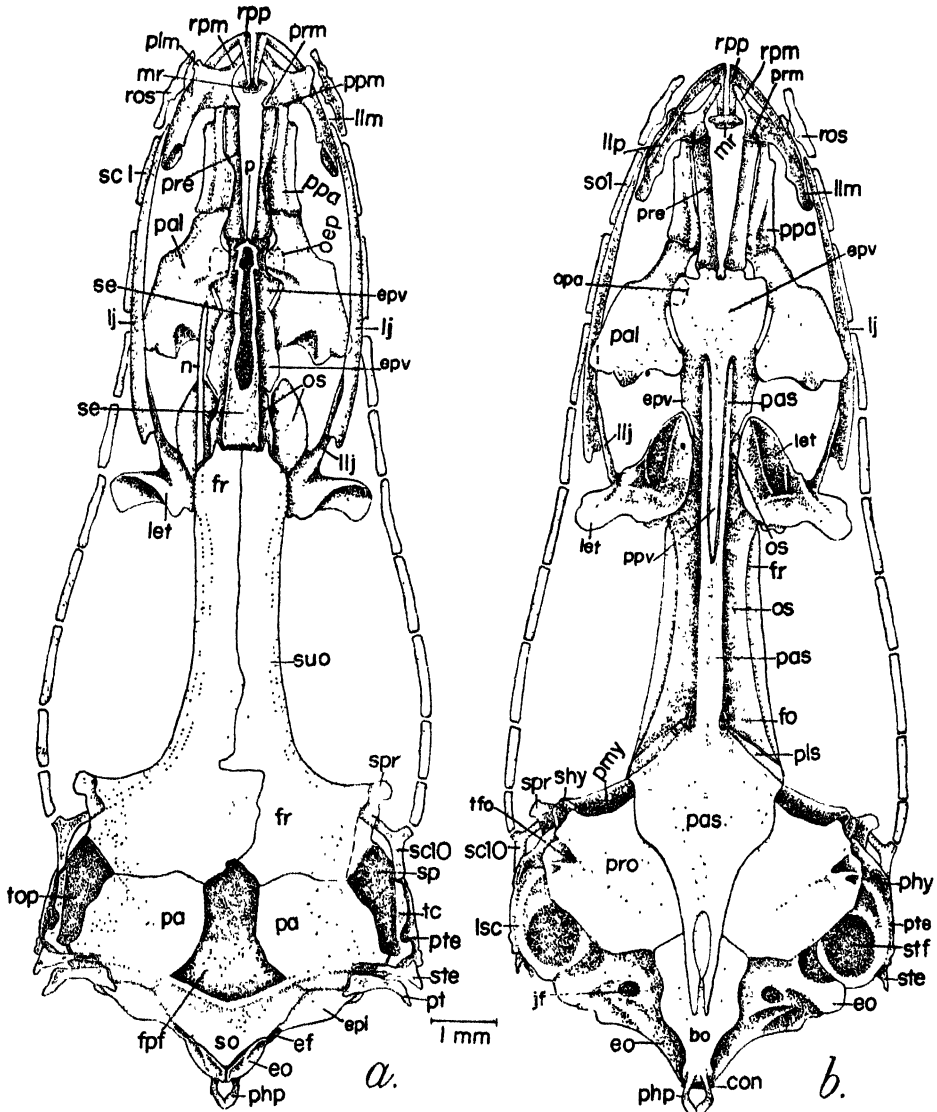
In *Nemachilus*, the gasbladder capsule is double, connected together by a posterior commissure following roughly the contour of the bladder itself. There is also a posterior portion of the bladder free of any osseous covering. In *Nemachilus dayi* (Text-fig. 7c), the anterodorsal and anteroventral portions of the gasbladder capsule appears to be formed by the dorsal (*dr2*) and pleural ribs respectively of the second vertebra; the posterodorsal and postero-ventral portions of the capsule are formed by the dorsal ribs (*dr1*) of the fourth vertebra. The region of the capsule near the united centra of the second and third vertebrae is probably formed by the pleural ribs (*ossa suspensoria*) and I am not able to follow this in my preparation on account of the absence of any demarcations. The centrum of the first vertebra with its dorsal ribs (*dr1*), and the neural arches of the second (*na2*), third (*na3*) and fourth (*na1*) vertebrae are clearly made out; however, the lateral openings are not seen in the view drawn.

The characteristic ossicles are noticed: the claustrum, scaphium, intercalarium and the tripus. The tripus is Y-shaped with the lateral limb of the fork short and this represents the processus anterior; the other limb comes in contact with the centrum as processus articularis. The posterior limb is also short and comes in contact with the gasbladder and there is no transformator process.

The second example that I have studied under *Nemachilini* is *Adiposia*. I shall only refer to the important characters in which the second genus resembles or differs from *Nemachilus*.

In the ethmoid region of *Adiposia*, the supraethmoid shows anteriorly a depression. The prepalatine articulates with the maxilla by a special facet. Sitting on the preethmoid, there is a small rounded sesamoid bone as in *N. dayi*;

Of the two species of *Diplophysa*, *stewarti* is smaller than *papilloso-labiata*. In the ethmoid region, the supraethmoid is slightly developed in *D. stewarti* and *Nemachilichthys* (Text-fig. 8a, se); there is also a depression anteriorly in it. In *D. papilloso-labiata* the supraethmoid is broad (Text-fig. 9, se) with winglike



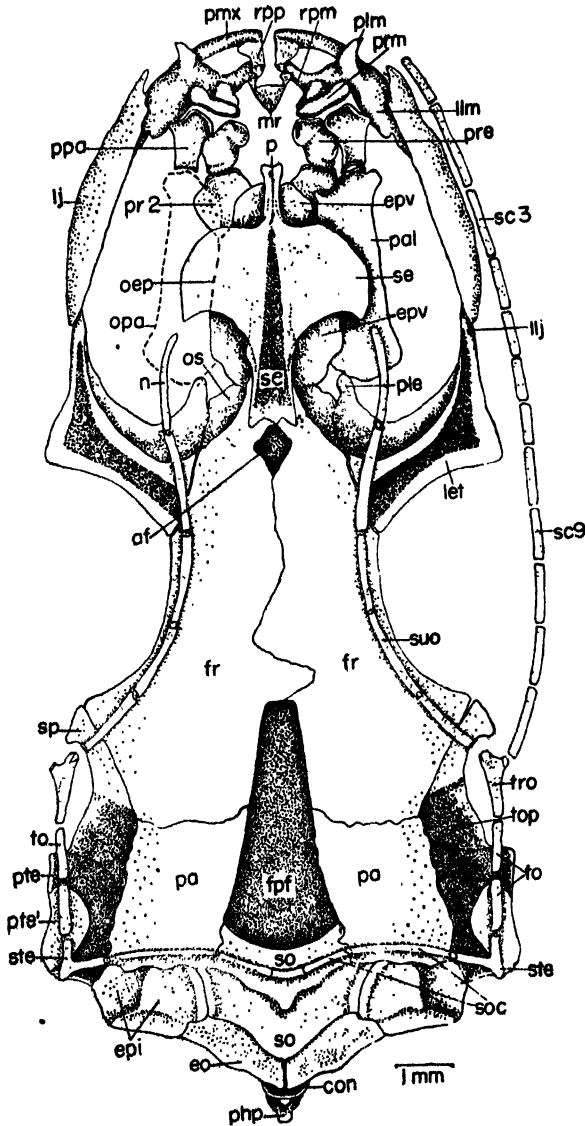
TEXT-FIG. 8. The skull of *Nemachilichthys ruppelli* (Sykes).
(a) Dorsal aspect (nasal is shown on one side only).
(b) Ventral aspect (nasals are not shown).

extensions anterolaterally and there is a large process (*p*) anteriorly. There is a median depression in the bone.

The preethmoid does not articulate with a prevomerine projection as in *N. dayi* and *Nemachilichthys* (Text-fig. 8a) but with a second preethmoid (Text-fig. 9, *pr2*)

in *Diplophysa*. The occurrence of a second preethmoid is noticed in *Diplophysa* as in some species of *Nemachilus* examined.

The maxillae and premaxillae (Text-fig. 8a) show the usual processes; in *Diplophysa* (Text-fig. 9) the single facet (*prm'*) of the maxilla for the prepalatine and preethmoid is obliquely elongated.



TEXT-FIG. 9. Dorsal aspect of the skull of *Diplophysa papilloso-labiata* Kessler. (The sub-orbital sensory canal is shown on one side only).

The lateral ethmoid (Text-fig. 9, *let*) in *D. papilloso-labiata* is large; mesially it comes in contact with the orbitosphenoid (*os*) and there is also an anterior projection (*ple*) of the lateral ethmoid in this region. There is a short process (*lj*) towards the lacrimojugal (*lj*). In *Nemachilichthys* (Text-figs. 8a, 8b) this process

(*lj*) is very long. In these two genera, the sensory canal bones are separate from the lacrimojugal.

In the orbitotemporal region, a supraorbital is absent in *Nemachilichthys* and *Diplophysa*.

Between the large frontals and the small parietals, there is the large frontoparietal fontanel (Text-figs. 8a, 9, *fpf*) in both *Nemachilichthys* and *Diplophysa*. In *D. papilloso-labiata* there is also an anterior fontanel (Text-fig. 9, *af*) between the two frontals just posterior to the supraethmoid articulation.

On the ventral aspect, the broader posterior portion of the parasphenoid gives rise to the lateral limbs to delimit the openings for the trigeminofacial nerves in *Diplophysa*; such a lateral limb is absent in *Nemachilichthys* (Text-fig. 8b).

In the auditory region, the sphenotic has a blunt sphenotic process (Text-figs. 8a, 8b, 9, *spr*) and dorsally, the posterior portion of the sphenotic along with the pterotic shows a depression in *Diplophysa* and *Nemachilichthys*; this depression is the temporal opening or fossa (Text-figs. 8a, 9, *to*). In *D. papilloso-labiata* a portion of the pterotic (*pte'*) extends over the fossa below the temporal sensory ossicles forming a part of the roof for the fossa. This fossa, as already said, is for the attachment of muscles. The epiotic of *D. papilloso-labiata* also shows a deep depression towards the fossa in the pterotic. On the ventral aspect the pterotic discloses a subtemporal fossa, poorly developed in *Diplophysa* but very well formed in *Nemachilichthys*, (Text-fig. 8b, *stf*) resembling the cyprinid condition.

In the jaws of *Diplophysa* and *Nemachilichthys*, the hyomandibula shows a prominent symplectic and a preopercular process; an opercular process is, however, wanting. In the lower jaw, *Nemachilichthys* is peculiar in having a ventral sensory canal in the dentary.

DISCUSSION.

Skull and the Associated Characters.

It is well established that the family Cobitidae falls into two very sharp groups with reference to the movability or otherwise of the ethmoid region over the frontals as recorded by Regan (1911). The Cobitidinae (Cobitini plus Botini) comes under the first category while in the Nemachilinae, the ethmoprevomer is firmly united with the frontals.

A supraethmoid is just indicated in *Cobitis* while in examples like *Acanthopsis*, *Acanthophthalmus*, *Lepidocephalichthys*, *Somileptes* and *Misgurnus*, it is not at all developed; in Botini there is a slight enlargement of the median septum to indicate a supraethmoid with a gully in it resembling more *Cobitis*. Sagemehl (1891) described that in *B. M'Clellandi*, the supraethmoid part was reduced. In *Nemachilus* and *Nemachilichthys*, a supraethmoid part could be clearly made out with an anterior depression; however, in *N. barbatus* and *microps*, this depression is absent. In the latter species of *Nemachilus*, the supraethmoid shows anteriorly slight wing-like extensions. In *D. papilloso-labiata* the supraethmoid is very broad and wing-like anteriorly and there is a prominent median process. In the other cyprinoid families, viz., Cyprinidae, Gyrinocheilidae, Psilorhynchidae and Homalopteridae the ethmoprevomer septum enlarges dorsally into a platelike supraethmoid which forms a mesial roof for the olfactory organs.

The most remarkable feature in the ethmoid region of the Cobitidae is the union of the ethmoid with prevomer to form a composite bone, a feature also recorded by Sagemehl (1891). I have called this united bone the ethmoprevomer. There are two projections from the anterior end of the prevomerine portion of the bone for articulation with a pair of preethmoids. This union of the ethmoid and the prevomer is probably an environmental adaptation for obtaining a certain amount of rigidity of the ethmoid region, for, these fish live among pebbles and shingles. Peculiarly such a union of the ethmoid and prevomer is not noticed

among the Homalopteridae and Gastromyzonidae (Ramaswami, 1948) dwelling in fast-running brooks, where obviously a certain amount of flexibility of the anterior region is necessary.

The preethmoid presents a peculiar condition. In the Cobitini like *Acanthopsis*, *Acanthophtalmus*, *Somileptes*, *Misgurnus* and *Lepidocephalichthys* there is a bone on either side of the ethmoprevomer; anteriorly, it articulates with the maxilla and posteriorly with the palatine by a large facet and with the prevomerine projection by another. In Botini and Nemachilini, there are two pairs of bones in the region occupied by the single preethmoid of the Cobitini. Of these, one is dorsal and spans between the maxilla and palatine and is called the prepalatine; the other extends between the maxilla and the prevomerine facet and this is the preethmoid. However, in a few examples like *N. barbatula*, *microps*, *botia* and *D. stewarti* and *papilloso-labiata*, the arrangement of bones in this region is different from what is noticed in Botini and other Nemachilini. In the above examples there are two preethmoids: a posterior smaller one which articulates with the lateral aspect of the ethmoprevomer (the 'septomaxilla' of Sagemehl, 1891) and the second anterior rounded rod which connects the second preethmoid and the maxilla (the 'sub-maxillary' of Sagemehl). Between the palatine and the maxilla, sitting on the first preethmoid is the prepalatine. I have pointed out elsewhere (Ramaswami, 1952c, 1952d) that it is 'very likely that the preethmoid found in the Cobitini has given rise, by a process of splitting, to the condition found in the above two genera and also to that in the Botini and other Nemachilini. However, in the Botini and Nemachilini examined (with the exceptions mentioned above) a second preethmoid is *not* developed and the prevomerine portion of the united ethmoprevomer gives articulation to the elongated preethmoid. It is interesting to note that in the Homalopteridae (Ramaswami, 1952c) and Gastromyzonidae (Ramaswami, 1952d), a second preethmoid is always developed.

The premaxillae of the Botini are different from those of the rest of the Cobitidae. The rostral process of the premaxilla arises not from the anterior end of the bone but from the middle, so much so there is an archlike process of the bone in front for supporting the tuft of barbels.

In the orbitotemporal region, the lateral ethmoid again shows difference in structure. While the bone is well developed in the Cobitini and Botini, it is generally small and always without a suborbital spine in Nemachilini; in the larger species like *N. microps* and *D. papilloso-labiata* the bone is quite large. However, the Cobitid *Misgurnus* also lacks a spine. The lateral ethmoid articulates with the orbitosphenoid ventrally and also with the frontal in the Cobitidae. While the lateral ethmoid gives rise anterolaterally to a small or large lacrimojugal process with which the lacrimojugal comes in contact, in *N. botia*, a lacrimojugal process of the lateral ethmoid is absent and the broad lacrimojugal comes in intimate contact with the lateral ethmoid by its posterior edge. Generally, in front of the lacrimojugal there is a sensory canal ossicle,—the rostral. In *N. barbatulus*, the lacrimojugal and rostral have united into a single ossification.

The Cobitini show a broad or a thin archlike supraorbital; the bone is absent in Botini and Nemachilini. Chranilov (1927, 1927a) also did not delineate a supraorbital in *N. barbatulus* described by him; however, a tiny supraorbital (orbitale) is drawn by him in *Lefua costata* (1927a, fig. 4, below). A supraorbital is also absent in the majority of Gastromyzonidae (Ramaswami, 1952d) while it is prominently present in the Homalopteridae (Ramaswami, 1952c).

In the Cobitidae the orbitosphenoids have united together into a single bone, a unique feature noticed nowhere else among the Cyprinoids. Moreover, it projects anteriorly on either side of the ethmoprevomer and peculiarly in Botini, the lateral ethmoid gains articulation with a special facet of the orbitosphenoid. The occurrence of a united orbitosphenoid appears to be as distinguishing a character of the Cobitidae as that of the united ethmoprevomer.

In some examples of Cobitini (*Acanthopsis*, *Acanthophthalmus*), the frontal and parasphenoid extend in front of the pleurosphenoid and keep the latter out of the orbit. In the other Cobitini (*Lepidocephalichthys* etc.) the pleurosphenoid is noticed in the posterior wall of the orbital region differing thereby from the above Cobitini.

In the auditory region, the Cobitini show peculiarities. In *Acanthopsis*, *Acanthophthalmus* and *Lepidocephalichthys* an epiotic is wanting and in the former two examples, the subtemporal fossa is also absent. In the other Cobitini, an epiotic is developed and the subtemporal fossa may be poorly developed (except *Somileptes*) as in Botini and a number of Nemachilini; however, the subtemporal fossa is well developed in the nemachiline *Nemachilichthys*. In this feature it resembles the Gyrinocheilidae (Ramaswami, 1952) and Homalopteridae (Ramaswami, 1952c). While in the Homalopteridae the subtemporal fossa is well developed, in the majority of the Gastromyzonidae (Ramaswami, 1952d) it is a shallow depression. In the Cobitini and Botini the pharyngeal processes do not unite below the aorta; in Nemachilini, there is union.

In the Cobitini, the members show such extraordinary variation in their skull structure that the group appears to be polyphyletic. Among the genera examined by me, *Acanthopsis*, *Acanthophthalmus* and *Lepidocephalichthys* show a conical skull with the posterior portion somewhat cylindrical and the skull lacks epiotics and the subtemporal fossae. In *Cobitis*, *Somileptes*, and *Misgurnus* the skull is depressed and the epiotics and subtemporal fossae are present. It may not be possible to explain these differences in skull structure in the Cobitini unless it is assumed that the group is polyphyletic; of the examined genera, *Acanthopsis*, *Acanthophthalmus* and *Lepidocephalichthys* have to be treated separately from *Cobitis*, *Somileptes* and *Misgurnus*.

Sagemehl (1891) referred to a 'temporalhöhle' in the dorsal pterotic region of Botini and some Nemachilini. He recorded (p. 552) that the temporal opening referred to above was absent in the genera *Nemachilus*, *Misgurnus*, *Cobitis* and *Acanthophthalmus*. Chranilov (1927, 1927a) also did not show the 'temporalhöhle' in his figure of *N. barbatulus* and the same figure has been copied by Berg (1940, p. 267, fig. 155). In my preparation of the several species of *Nemachilus* and *Cobitis taenia*, the temporal opening is, however, clearly seen. This is a depression in the pterotic roof mostly for the attachment of certain muscles and is roofed by the mesial limb of the supratemporal ossicle and the posttemporal. In *Acanthopsis*, *Acanthophthalmus*, *Somileptes*, *Misgurnus* and *Lepidocephalichthys*, this depression is wanting.

Misgurnus differs from the other Cobitini in two important features. Firstly it lacks a suborbital spine so characteristically seen in other Cobitini. In the upper jaw of *Misgurnus* the metapterygoid is large showing a large foramen in it as delineated in Fig. 158 (p. 270) by Berg (1940) which is a reproduction from Chranilov (1927, 1927a). But in his description, Berg stated that the foramen was between the quadrate and the metapterygoid. In the other Cobitini like *Lepidocephalichthys* and *Acanthopsis*, the metapterygoid is deeply indented towards the quadrate and the latter bone also shows an indentation and this large gap between the bones is probably the foramen referred to by Berg (1940) between metapterygoid and quadrate.

In the Cobitini the supraorbital, suborbital and temporal sensory canal ossicles are all independent and disunited with the bones on which they rest and they can be easily taken off from the skull; a mandibular sensory canal is also seen. The first ossicle of the supraorbital series is the nasal situated on the mesial aspect of the nares. In Botini, in the orbital region of the frontal bones, the supraorbital canal passes within the bone and the occipital canal also passes similarly. In the Nemachilini, the supraorbital and suborbital canal ossicles are independent of the skull bones. However, in *Nemachilichthys* the supraorbital sensory canal passes

through the frontals and the temporal ossicle is fused with the pterotic; the occipital canal is also intraosseous.

The bones of the lower jaw of Cobitidae, apart from showing difference in shape, also differ in disposition. In the Cobitini the angular and dentary are loosely articulated and the mesial sesamoid angular is absent. In the Botini and Nemachilini, the angular and dentary are firmly articulated and there is a mesial sesamoid angular. Generally a set of sensory canal bones run by the side of the lower jaw bones.

Gasbladder capsule and the weberian ossicles.

Chranilov (1927) described the gasbladder capsule and the weberian ossicles in a number of genera belonging to the three subfamilies. According to him, the structural arrangement of parts falls into two types. In the first the gasbladder capsule may show an upper smaller and a lower larger-portion as in *Misgurnus*, *Cobitis*, *Lepidocephalichthys* etc., where the capsule is built by the dorsal ribs [= transverse processes, parapophyses (Chranilov, 1927); parapophyses (Berg, 1940)] and ossa suspensoria (pleural ribs) of the fourth vertebra. In the second type, the gasbladder capsule is divided into right and left parts as in *Nemachilichthys*, *Nemachilus* and *Diplophysa* where the capsule is built by the ribs (dorsal and pleural) of the second and fourth vertebrae. Chranilov (1927) also pointed out that the structure of the capsule in a form like *Leptobotia* gave a clue as to how the second type could have evolved from the first.

I have been able to confirm the observations of Chranilov (1927) in the case of *Cobitis*, *Misgurnus* and *Lepidocephalichthys*; the same arrangement is also noticed in the other Cobitini examined by me like *Acanthopsis*, *Acanthophthalmus* and *Somileptes*.

Having examined three species of *Botia*, I am also able to confirm the observations of Chranilov (1927) with regard to Botini. In *Leptobotia* (Chranilov, 1927), the posterior portion of the gasbladder capsule is membranous while in *Botia*, the capsule is a pearshaped bony chamber.

I shall now describe the structure of the gasbladder capsule and the weberian ossicles which show differences in the three subfamilies of the Cobitidae. In the Cobitini, the dorsal ribs of the second vertebra are large and free; the pleural ribs may bound anteriorly the large lateral opening (= 'introitus' or apertura magna externa). The dorsal ribs of the fourth vertebra form the roof of the lateral opening and partly extend on the sides as spines, the gasbladder capsule being formed by the ossa suspensoria (pleural ribs). In the Botini, while the second pair of dorsal ribs are free, the pleural ribs take part in bounding the capsule wall anteriorly; the dorsal ribs of the fourth vertebra project over the large lateral fenestra and also extend laterally to end as spines as in Cobitini. The ossa suspensoria form the walls of the capsule. In *Leptobotia* the capsule is membranous posteriorly but in *Botia*, it is completely osseous and no opening is noticed posteriorly as in *Somileptes* or *Lepidocephalichthys* for connecting the posterior portion of the gasbladder. In both Cobitini and Botini, the capsular gasbladder is single. In the Nemachilini, it is divided into right and left halves and connected together by a posterior commissure. Chranilov's figure (1927, Fig. 11) of the gasbladder capsule of *Diplophysa strauchii* also copied by Berg (1940, Fig. 156) and labelled as that of *Nemachilus strauchii* gives an impression that the anteroventral portion of the gasbladder capsule is formed by the pleural ribs of the second vertebra while the more mesial portion of the same region is formed by the projections of the second pair of dorsal ribs; the remaining portion of the covering is formed by the dorsal ribs of the fourth vertebra and near the united centra of the second and third vertebrae, by the pleural ribs of the fourth vertebra (ossa suspensoria). But my examination of the gasbladder capsule of *Diplophysa stewarti*, *D. pailloso-labiata*, *Nemachilus dayi*, *N. botia*, *N. rupicola*, *N. microps* and *Nemachilichthys* has disclosed that dorsally the osseous

covering of the gasbladder capsule is composed of two parts separated by a suture; the anterior part appears to be formed by the second pair of dorsal ribs while the larger posterior is formed by the dorsal ribs of the fourth vertebra. Similarly, on the ventral aspect, the anterior part is formed by the second pair of pleural ribs and the posterior part by the dorsal ribs of the fourth vertebra and the mesial wall of the capsule near the centra being formed by the pleural ribs or ossa suspensoria, though the demarcations are not visible.

The first centrum is free in the Cobitidae and is generally opisthocelous. It carries a small or large pair of dorsal ribs. Peculiarly, the dorsal ribs of the first vertebra unite at their tips with the gasbladder capsule in some *Gastromyzonidae* (Ramaswami, 1952*d*).

The centra of the second and third vertebrae are fused in the Cobitidae. While it may be possible to distinguish the outlines of articulations of the centra in some (*Leptobotia*), in others it is not possible (*Botia* etc.). The centrum of the second vertebra carries a pair each of dorsal and pleural ribs. The dorsal ribs are free in Cobitini and Botini while in *Nemachilini*, they form the anterodorsal wall of the osseous capsule. The pleural ribs may form the anterior boundary of the lateral opening (Cobitini) or they may help to form the capsule wall (Botini and *Nemachilini*).

The third centrum does not bear any ribs or parapophyses.

The fourth centrum is independent and is amphicoelous. The dorsal, and pleural ribs (ossa suspensoria) of this vertebra take part in the formation of the remaining portion of the osseous capsule wall.

That the so-called 'transverse processes' alluded to by workers on the Ostariophysian gasbladder capsule are not really those, is undoubted. A true transverse process is a diapophysis from the neural arch while the so-called 'transverse process' of the fishes is a basiventral projection plus the dorsal rib of the segment (Watson, 1939). The transverse process as described by Chranilov (1927), probably represents an united parapophysis and the dorsal rib. Mookerjee and Mookerji (unpublished thesis, 1950)* confirmed the observation of Watson in stating that the so-called transverse process in the carp-minnow (*Esomus*) which they studied, was the united basiventral and the dorsal rib. The other structure which has been labelled 'rib' by Chranilov (1927) and Berg (1940) represents the pleural rib. In the fourth vertebra, the pleural ribs are modified into the ossa suspensoria and Watson (1939), however, considered these as haemapophyses. Nelson (1948) described in the *Catostomidae* and also in the *Cyprinidae*, the large ventrolateral projection from the fourth centrum as pleural rib while all previous workers like Chranilov (1927), Sarbahi (1933) and Berg (1940) do not consider it so and both Chranilov and Berg regard the ossa suspensoria as pleural derivatives.

The weberian ossicles of Cobitidae has been described by Chranilov (1927). While the structure of the first three ossicles (claustrum, scaphium and intercalarium) are almost the same in the three subfamilies, that of tripus differs. In the Cobitini and Botini, the tripus is broadly triangular with the anterior and articular processes differing in size. In the *Nemachilini*, the tripus is Y-shaped with one of the anterior limbs short and this represents the processus anterior; the other limb comes in contact with the centrum as processus articularis. The posterior limb is very short and comes in contact with the gasbladder and there is no transformator process.

I am unable to comment upon the derivation of the ossicles, as I have not been able to study their developmental history.

Adiposia was made the type of a suborder *Adiposidae* by Jordon since the fish showed an adipose dorsal but was subsequently merged in the genus *Nemachilus*. Berg (1940) also treated the genus *Adiposia* as congeneric with *Nema-*

chilus (Hasslt.). A study of the skeletal characters of *Adiposia* has shown that it resembles *Nemachilus* very closely and therefore, it is rightly merged in *Nemachilus*.

Similarly, *Cobitis barbatulus* in its cranial organisation resembles *Nemachilus* and therefore, cannot be treated as a member of Cobitini and is correctly described by systematists as *N. barbatulus*.

With regard to the species of *Diplophysa* and *Nemachilus* that I have studied, *Diplophysa* shows an arrangement of bones in the skull similar to *Nemachilus*. I have noticed only two differences in the ethmoid region of the examined species of *Diplophysa* and *Nemachilus*. In the latter genus, only two species (*microps*, *botia*) show the occurrence of a second preethmoid and only one species (*microps*) shows the broadening of the anterior supraethmoid region. Berg (1940) treated *D. struachi* as a synonym of *N. struachi* (Kessl.) and it is very likely that other species of *Diplophysa* may also be merged under those of *Nemachilus*. In fact Berg (1940, p. 270) treated the entire genus *Diplophysa* as a synonym of *Nemachilus* as was previously done by Hora (1930). As far as I could judge from a study of the skull and gasbladder capsule of the examined species of *Diplophysa* and *Nemachilus*, I find that the two genera resemble each other in all important characters.

In assessing the relationship of the Cobitidae with the Homalopteridae and Gastromyzonidae, it is noticed that the former differs from the latter two in the possession of (1) a united ethmoprevomer, (2) a united orbitosphenoid, and (3) the pharyngeal processes united or disunited below the aorta. But all the Homalopteridae and Gastromyzonidae resemble the Nemachilini cobitids in the structure of their gasbladder capsule and the weberian ossicles. Moreover the gastromyzonids resemble the nemachilini cobitids generally in the poorly developed supraethmoid portion and the subtemporal fossae, in the ento-meta-pterygoid ridge and in the linear elongation of the operculum. The Bornean Gastromyzonid *Ghaniopsis* also shows the sensory canal ossicles disunited from the bones on which they are located. Peculiarly, a few species of *Nemachilus* and of *Diplophysa*, in addition to the resemblances enumerated above, also show the occurrence of the second preethmoid commonly met with in the Gastromyzonidae. Therefore, it is clear that the Gastromyzonidae resemble more the nemachiline subdivision of the Cobitidae but the differences, few as they may be, are so poignant that the Gastromyzonidae cannot be derived directly from Cobitid ancestors. The Gastromyzonidae (Ramaswami, 1952d) has already been shown to be diphyletic in origin, the Bornean genera evolving independently of the mainland or Chinese forms. The Bornean *Ghaniopsis* (Gastromyzonidae) in showing a number of internal and external nemachiline features (Hora and Jayaram, 1951; Ramaswami, 1952d) has probably taken its origin from the same ancestral stock as that of the Cobitidae, and both *Ghaniopsis* and the Nemachilini genera have evolved parallelly. As the mainland fauna had no geographical continuity with the Bornean, the Chinese genera of the Gastromyzonidae must have evolved from a different ancestor, probably from a Crossostomid one. This ancestor also probably took its origin from the same stock. As already indicated by me (Ramaswami, 1952d), it is not possible to derive the Gastromyzonidae from a Cyprinid ancestor and therefore, the Gastromyzonidae must have taken their origin from a stock common to the Cyprinidae and the Cobitidae, and must have evolved parallelly with the Nemachilini (Cobitidae) as did the Homalopteridae with the Cyprinidae.

SUMMARY.

1. The skull and the gasbladder capsule of eleven genera belonging to the three subfamilies of Cobitidae have been studied and described.
2. The Cobitid genera show in their skull uniformly a united ethmoprevomer and a united orbitosphenoid.
3. The ethmoid region of Cobitini differs from that of Botini and Nemachilini. In the Cobitini, on either side of the ethmoprevomer, a preethmoid articulates anteriorly with the

maxilla and posteriorly with the ethmoprevomer and palatine independently; in Botini and Nemachilini there are in this region two bones. The dorsal one is the prepalatine, while the other is the preethmoid. It is argued that the single preethmoid of Cobitini has given rise, by a process of splitting, to the two bones seen in Botini and Nemachilini.

4. The lateral ethmoid is built on a common plan in Cobitini and Botini. In the two subfamilies, a number of spinelike processes are noticed and one of them is the suborbital spine which is of great systematic importance. *Misgurnus* is peculiar in lacking a suborbital spine. In Nemachilini, the bone is smaller and is devoid of a spinelike process.

5. The lacrimojugal may be well or poorly developed. In *Nemachilus botia*, the bone is very broad and articulates with the lateral ethmoid. In *N. barbatulus*, the lacrimojugal is united with the anterior rostral to form a lacrimojugal-rostral.

6. The premaxillae of Botini differ from those of the other two subfamilies. In *Botia* the rostral processes arise from the middle of the premaxilla instead of the anterior tip.

7. The supraorbital bone is present generally in Cobitini (however it is not shown by Chranilov (1927a) in his fig. 6 above); it may be broad as in *Cobitis* or like a bow as in *Acanthopsis*, *Acanthophthalmus*, etc.

8. The supraorbital, suborbital and temporal sensory canal ossicles are disunited with the underlying bones in Cobitini and Nemachilini; however, in *Nemachilichthys*, the supraorbital, temporal and occipital canals run within the bones in those regions. In Botini also the supraorbital and occipital canals run within bones and there is a single elongated temporal ossicle in front of the supratemporal.

9. The Cobitini appear to be polyphyletic. *Acanthopsis*, *Acanthophthalmus* and *Lepidocephalichthys* do not show in the auditory region the epiotics and subtemporal fossae; in *Cobitis*, *Somleptes* and *Misgurnus*, they are developed.

10. In the structure of the jaws, the Cobitini show peculiarities. There is a large gap between the metapterygoid and quadrate and the entopterygoid is rodlike. A sesamoid angular is absent in the lower jaw of Cobitini; it is well developed in Botini and Nemachilini.

11. The pharyngeal processes are disunited in Cobitini and Botini while in Nemachilini, they unite below the aorta.

12. The gasbladder capsule is single in the Cobitini and Botini. In the Cobitini, there is a posterior opening in the capsule; this is absent in *Botia*. In the Nemachilini, the gasbladder capsule is divided into right and left portions connected by a commissure. In the Cobitini and Botini, the capsule is formed by the fourth pair of dorsal ribs and ossa suspensoria (= pleural ribs of the fourth vertebral). In Nemachilini the capsule is formed by the dorsal and pleural ribs of the second and fourth vertebrae. The tripus is broadly triangular in the Cobitini and Botini while in Nemachilini, it is triradiate.

13. *Adiposia* and *Diplophysa* are closely allied to *Nemachilus* and craniology supports the merging of the two in *Nemachilus*.

14. The study of Cobitid skeleton amply supports the division of the family into three subfamilies, viz., Cobitini, Botini and Nemachilini.

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KEY TO LETTERING.

af = anterior fontanel; *ame* = apertura magna externa; *an* = angular; *ap* = articular process; *apm* = anterior process of maxilla; *aq* = articular facet of lower jaw for quadrater; *aql* = articular facet of quadrate for lower jaw; *aup* = auricular process; *ao* = groove for passage of aorta; *bo* = basioccipital; *cl* = claustrum; *con* = condyle; *c1, c4* = centra of first and fourth vertebrae; *den* = dentary; *dp* = dorsal process of dentary; *dpm* = dorsal process of maxilla; *dr1, dr2, dr4* = dorsal ribs of first, second and fourth vertebrae; *ecp* = ectopterygoid; *ef* = exoccipital fenestra; *enp* = entopterygoid; *eo* = exoccipital; *epi* = epiotic; *epp* = ethmoid process of palatine; *fm* = foramen magnum; *fo* = foramen opticus; *fpf* = frontoparietal fontanel; *fr* = frontal; *fr'* = lateral process of frontal; *gbc* = gasbladder capsule; *hy* = hyomandibula; *int* = intercalarium; *iol* = interopercular; *jf* = jugular foramen; *les* = lateral extrascapular; *let* = lateral ethmoid; *lj* = lacrimojugal; *ljr* = lacrimojugal-rostral; *llj* = lateral ethmoid process towards lacrimojugal; *llm* = lateral limb of maxilla; *llp* = lateral limb of premaxilla; *lsc* = lateral semicircular canal enlargement; *mp* = metapterygoid; *mr* = median rostral; *n* = nasal; *na2, na3, na4* = neural arch of second, third and fourth vertebrae; *ns2, ns3, ns4* = neural spine of second, third and fourth vertebrae; *ns23* = united second and third neural spines; *ob* = outline of sesamoid bone; *oec* = outline of ectopterygoid; *oep* = outline of ethmoprevomer; *oio* = outline of interopercular; *ole* = outline of lateral ethmoid; *olj* = outline of lacrimojugal; *on* = outline of nasal; *op* = opercular; *opa* = outline of palatine; *opm* = outline of posterior process of metapterygoid; *opo* = outline of preopercular; *opp* = outline of prepalatine; *oro* = outline of rostral; *os* = orbitosphenoid; *osn* = orifice for spinal nerve; *oso* = outline of subopercular; *oss* = ossa suspensoria; *p* = ethmoprevomerine process; *pa* = parietal; *pal* = palatine; *pas* = parasphenoid; *pen* = articular facet of entopterygoid for palatine; *pfm* = preethmoid facet for maxilla; *pfp* = preethmoid facet for palatine; *pfv* = preethmoid facet for ethmoprevomer; *ph* = hyomandibular facet for pterotic articulation; *pho* = hyomandibular projection towards the operculum; *php* = pharyngeal process; *phy* = pterotic facet for hyomandibula; *ple* = lateral ethmoid projection towards palatine; *plm* = process of maxilla for adductor ligament; *plp* = process of pleurosphenoid towards sphenotic process; *pls* = pleurosphenoid; *pl2* = pleural rib of second vertebra; *pmp* = posterior process of metapterygoid; *pmx* = premaxilla; *pmy* = posterior myodome; *po* = posterior opening in gasbladder; *pop* = preopercular; *ppa* = prepalatine; *pph* = hyomandibular facet towards preopercular; *ppm* = maxillary facet for prepalatine; *ppq* = posterior process of quadrate; *ppv* = posterior process of prevomerine portion of ethmoprevomer; *pr* = lateral process of median rostral; *pre* = preethmoid; *pr'm* = facet of maxilla for preethmoid and prepalatine; *pro* = prootic; *pr2* = process

from the second dorsal rib; *pr2'* = second preethmoid; *pr4* = process from the fourth dorsal rib; *pt* = posttemporal; *pte* = pterotic; *pte'* = pterotic roof over temporal opening; *pv* = prevomerino portion of ethmoprevomer; *q* = quadrate; *ra* = retroarticular; *ros* = rostral; *rpm* = rostral process of maxilla; *rpp* = rostral process of premaxilla; *ri* = ridge on the metapterygoid; *ri'* = ridge on the orbitosphenoid; *san* = sesamoid angular; *sb* = sesamoid bone; *sc* = sensory canal ossicle; *sca* = scaphium; *scd* = sensory canal in dentary; *sc1*, *sc3*, *sc9* = first, third and ninth suborbital sensory canal ossicle; *sc10* = tenth sensory canal ossicle; *se* = supraethmoid; *sh* = sphenotic facet of hyomandibula; *shy* = facet in sphenotic for hyomandibula; *so* = supraoccipital; *soc* = supraoccipital sensory canal ossicles; *soo* = suborbital ossicles; *sop* = subopercular; *sor* = supraorbital; *sp* = sphenotic; *sph* = symplectic process of hyomandibula; *spo* = sensory canal in preopercular; *spr* = sphenotic process; *ssp* = subocular spine of lateral ethmoid; *ste* = supratemporal; *stf* = subtemporal fossa; *suo* = supraorbital sensory canal; *sym* = symplectic; *tc* = temporal canal; *tfo* = trigeminofacial opening; *to* = temporal sensory ossicle; *top* = temporal opening; *tri* = tripus; *tro* = triradiate temporal ossicle; *vdr4* = ventral portion of the roof of gasbladder capsule formed by the fourth pair of dorsal ribs.

ADDENDUM.

SYSTEMATICS OF THE FISHES OF THE FAMILY COBITIDAE.

As a result of the investigations reported above, the following observations may be recorded as regards the Systematics of the Cobitidae:

- (1) The Cobitidae, in spite of divergences necessitating grouping in three divisions, is a monophyletic family.
- (2) The Section Cobitini forms a composite group in which *Acanthopsis*, *Acanthophthalmus* and *Lepidocephalichthys* differ from *Cobitis*, *Somileptes* and *Misgurnus* in lacking epiotics and subtemporal fossae.
- (3) The genus *Adiposia* Annandale and Hora is craniologically a *Nemachilus* though in the development of an adipose dorsal it shows a physiological adaptation to the conditions under which it lives.
- (4) The genus *Diplophysa* Kessler is, like *Adiposia*, craniologically a *Nemachilus* though in the development of a second free air-bladder it shows an adaptation to the conditions of life in deeper waters.
- (5) As the presence or absence of a dorsal fin is a generic character among the Siluroids and other groups of fishes, *Adiposia* should not be suppressed but retained as a distinct genus under Nemachilini. There is, however, no justification to raise it to the rank of a family as was done by Jordon.
- (6) *Diplophysa* should also be regarded as a separate genus on the character of a second air-bladder free in the abdominal cavity besides the original bladder enclosed in bone.

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AN ALGAL FLORA FROM THE LAKI (LOWER EOCENE) BEDS OF THE NAMMAL GORGE (PUNJAB SALT RANGE). II. *MESOPHYLLUM*

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INTRODUCTION.

In a previous communication (Varma, 1952) the Geology of the algal-bearing beds of the Nammal Gorge ($32^{\circ} 40' : 71^{\circ} 48'$) and a description of the several species of *Archaeolithothamnium* occurring in these beds have been given. The genus *Mesophyllum*, which is represented by three species in the same (Sakesar limestone, Laki) bed of the Nammal sequence forms the subject matter of this paper.

THE GENUS *MESOPHYLLUM* LEM.

The genus was established in 1928 by Mme. Lemoine for forms which show characters intermediate between *Lithothamnium* and *Lithophyllum*. It resembles the former with regard to its conceptacles and their openings, as well as in the presence of growth-lines. The arrangement of the hypothallial and perithallial cells is similar to that of the genus *Lithophyllum*. The latter, however, lacks zonation and the sporangial conceptacles have a single opening on the roof while the cystocarpic conceptacles have more than one opening on the roof.

Defining the genus, Lemoine (1939, p. 80) states, 'Espèces crustacées ou ramifiées. Hypothalle de la croûte formé de rangées; exceptionnellement la disposition en rangées est peu apparente ou absente (Section IV). Tissu des mamelons et des branches divisé en zones; celles-ci formées de rangées. Conceptacles à sporanges munis dans le toit de plusieurs pores; conceptacles à cystocarpes avec un seul orifice'. From the definition as well as from a study of the various species of the genus it becomes clear that it shows the closest affinity with *Lithothamnium*, from which it differs only in the organization of the vegetative tissue. We can, however, observe a complete gradation from the *Lithothamnium* type to the *Lithophyllum* type of tissue among the various species of *Mesophyllum*. The fourth section of *Mesophyllum*, represented by *M. Laffitei* Lem., *M. Vaughani* (Howe) Lem. and *M. curtum* Lem., shows a disposition of the tissue where the arrangement of cells of the perithallium and hypothallium in rows is least apparent; then in *M. Gignouxii* Lem., a representative of the 1st section, the hypothallium shows a rowed arrangement whereas the perithallium shows a mixture of cells arranged in rows and files. A majority of *Mesophyllum* species representing the 2nd section show a well-defined vegetative tissue while in the 3rd section, represented by a single species *M. sp.* (1939, p. 80), the perithallium is peculiar in 'montrant une alternance dans la longueur des cellules'. A peculiarity which distinguishes *Mesophyllum* from *Lithophyllum* even when conceptacles are absent, is the presence of lines of growth resulting in a zonated perithallium. Very often a zig-zagging tendency is seen in the horizontal partitions of the medullary hypothallium of the branches and in the perithallium of the crusts. Zonation is also characteristic of *Lithothamnium* as defined by Lemoine (1939, p. 63) 'Hypothalle basilaire des croûtes formé de files, jamais par des rangées concentriques; des lignes ou des zones d'accroissement existent dans le

périthalle et le tissu des branches, dont les cellules ne sont pas, en principe, disposées en rangées; si cet aspect est réalisé *localement* dans certaines zones du tissu, les cloisons horizontales des cellules ne sont jamais soudées en une ligne continue.

Le toit des conceptacles à sporanges est traversé par de nombreux orifices; celui des conceptacles à cystocarpes par un orifice unique....'.

Mme. Lemoine considers the presence of the lines of growth or zonation in the vegetative tissue of such great importance that she has actually put into this genus certain forms previously described under *Lithophyllum*. The forms *Lithophyllum Koritzae* Lem. (1923) and *Lithophyllum Pfenderae* Lem. (1928) were later revised to *Mesophyllum Koritzae* Lem. and *M. Pfenderae* and she (1939, p. 87) remarks, 'Sous le nom de *Lithophyllum Pfenderae*, J'ai décrit en 1928 une coupe de branche du Lutétien de Catalogne; à cause de la présence de zones d'accroissement, cette espèce doit prendre place dans le genre *Mesophyllum*....'. Also, in quite a few cases the fragments have been designated to this genus without giving any information regarding the nature of the conceptacles, e.g. *M. tropicale* Lem. and *M. varians* Lem. (1934, pp. 276-277). *Lithophyllum* (?) *molare* Howe (1919, p. 15) which shows zonation has also been referred by Lemoine (1928, p. 253) to be a *Mesophyllum*.

An interesting observation in *Archaeolithothamnium digitatum* Pfender, also made by Lemoine (1939, pp. 44-45) is with regard to zonation in the medullary hypothallium of its branches and she has also figured one such specimen (p. 49, fig. 6) with characteristic sporangia of the genus. The presence of zonation in medullary hypothallium and perithallium has also been noticed by Howe in the Oligocene species *A. affine* Howe (1919, p. 11). Also, zones or lines of growth are well known to occur in *Lithothamnium*. In the light of some of the above facts it becomes clear that the presence of zonation is not confined to the genus *Mesophyllum* and the presence or absence of zonation a sufficient criterion to distinguish fragments of *Mesophyllum* from *Lithothamnium* and *Lithophyllum*. Instead, the lines of growth most probably may have something to do with the ecological factors, than be the expression of a genetic feature.

The effect of environments is very well known on the morphology of higher plants, which tends to show a more or less similar reaction to a particular ecological factor even in quite unrelated plants (Clements and others, 1950). It is possible that the morphological similarities among the co-existing algae may also be attributed to some ecological factors.

The question whether *Mesophyllum* should be regarded as a sub-genus under *Lithothamnium* or raised to generic rank as has been done by Lemoine deserves further considerations.

PREVIOUS RECORDS OF THE GENUS IN INDIA.

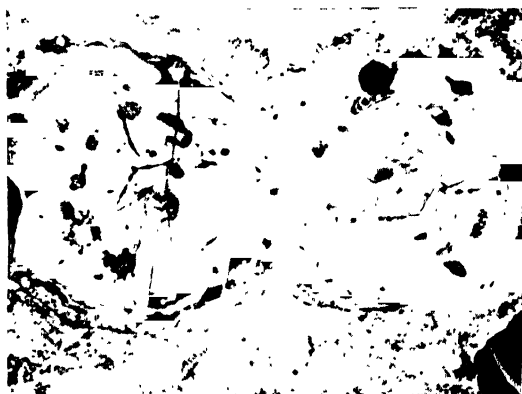
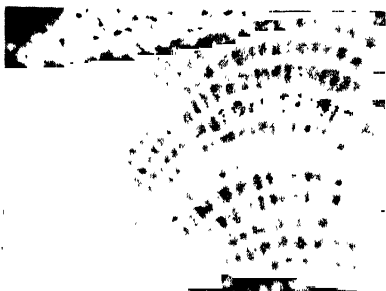
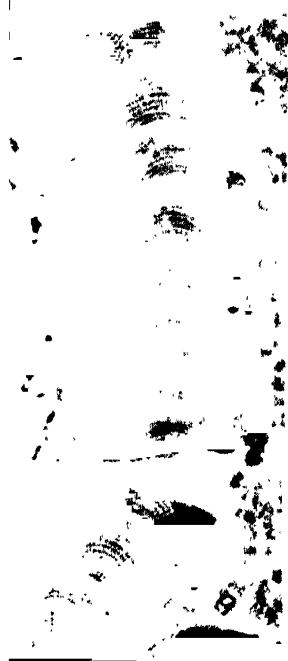
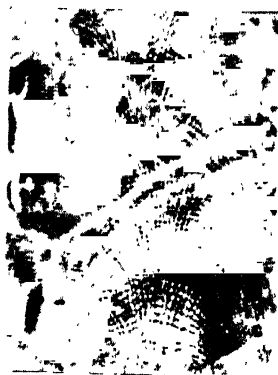
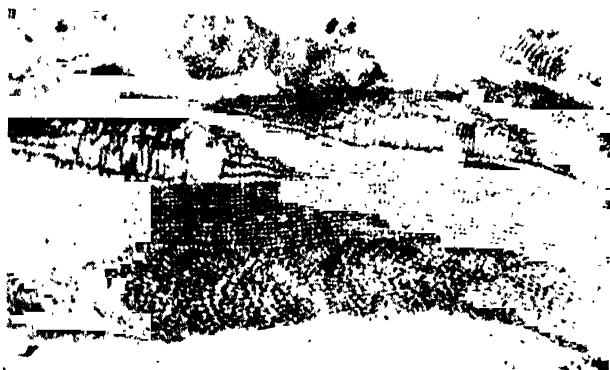
Mesophyllum is known to range from Cretaceous to Recent. About ten living forms have been referred to this genus by Lemoine of which *M. simulans* Fosl. and *M. australe* Fosl. are reported from the Indian Ocean (1928, p. 252). From India, Das-Gupta (1926, pp. 9-10, Pl. VI) described a form as a foraminifer under the name *Orthophragmina radians* from Khasi Hills, Assam. This has been referred by K. S. Rao (1943, p. 272) to a *Mesophyllum*. *M. daviesi* N. Rao (1941, p. 41) is known from the uppermost portion of the Lower Ranikot, Punjab, and the unidentified species of *Mesophyllum* (= *Orthophragmina radians* d' Archiac of Das-Gupta) has been described by K. S. Rao (1943, p. 283) from the early Tertiary rocks of Assam.

Mesophyllum lakiense sp. nov.

(Pl. XIV, figs. 1, 2, 3 and 6).

Diagnosis:

Thallus as mammillate crusts, occasionally branched; perithallium zoned, showing a clear lattice of mostly squarish cells; hypothallial cells of the crusts fan-



shaped. The medullary hypothallium zonated, and the concentric arrangement of cells with pronounced zig-zagging tendency. Conceptacles as laterally elongated domes, $82.5-99\mu \times 300-600\mu$.

Measurements:

Perithallial cells	.. $7.8-13\mu \times 7.8-13\mu$.
Hypothallial cells	.. $10.4-15.6\mu \times 7.8-11.7\mu$.
Conceptacles	.. $82.5-99\mu \times 300-600\mu$.

Description:

Thallus encrusting, mammillate and occasionally branched (0.5-2.8 mm. thick) and furcate (Pl. XIV, fig. 6). The hypothallial tissue of the crust shows the concentric arrangement typical of *Mesophyllum*, the cells range between $10.4-15.6\mu$ long and $7.8-11.7\mu$ broad, mostly $13\mu \times 10.4\mu$. The perithallium shows zonation with a well defined compact lattice of mostly squarish and occasionally rectangular cells. The flattening of these cells may occur horizontally or vertically. The conceptacles observed are up to 99μ high and extend laterally up to 600μ . Conceptacles both empty and those filled with cells are present. The number of pores in the roof of the conceptacles is not known.

Comparisons:

As previously indicated only two species of *Mesophyllum* have so far been described from India, both recorded from the Tertiary rocks. The two species of *Mesophyllum* that are now being described from the Lake (Lower Eocene) beds have been closely compared with the Tertiary species of the genus described from India and other countries (Lemoine, 1930, 1939).

Among the Indian forms *Mesophyllum* sp. (K. S. Rao, 1943, p. 283) from Assam is not a branched form and is clearly distinguished from *M. lakiense* sp. nov. by its elongated ovoid to slightly hemispherical shape of the conceptacles and by their size. The vegetative cells are also quite different in size (*M.* sp. K. S. Rao, perithallial cells $12-16\mu \times 11-13\mu$, hypothallial cells $12-28\mu \times 9-12\mu$, conceptacles $230-310\mu \times 130-140\mu$). *M. daviesi* N. Rao also differs in the size and shape of its vegetative and reproductive organs (perithallial cells $6.2-9\mu \times 12.4\mu$, hypothallial cells $7.7\mu \times 18.6\mu$, conceptacles biconvex $72.5\mu \times 160\mu$).

Mesophyllum lakiense sp. nov. fits better in the second section of Lemoine's table for the determination of Tertiary species of *Mesophyllum* (1939, pp. 80-22) which includes forms with hypothallium and perithallium of the crusts formed of rows of cells. Among the various species of the genus described under this section it could be compared with only those species which are represented in the form of branches also because *M. lakiense* sp. nov. is known to occur as crusts and branches. *M. commune* Lem. (1939, p. 81, 86) which is also represented in the form of crusts and branches differs with *M. lakiense* in the measurement of its vegetative and reproductive organs (perithallial cells $10-20\mu \times 5-12\mu$, hypothallial cells $15-33\mu \times 6-10-15\mu$, conceptacles $325-500\mu \times 125-175\mu$) and some other details.

Mesophyllum punjabense sp. nov.

(Pl. XIV, figs. 4 and 5; Pl. XV, figs. 5 and 6).

Diagnosis:

Thallus observed in the form of crusts and thin branches, perithallium showing a clear lattice of squarish-rectangular cells with lines of growth; medullary hypothallial cells with horizontal walls continued and concentric rows with unequal

zonation. The lines of zonation present an aspect of a row of smaller cells than the rest of the medullary hypothallial cells. In the crustaceous forms, hypothallium scanty and more or less fan-shaped while the perithallium possesses a clear lattice of cells. Conceptacles laterally ovoid to slightly dome-shaped, $99\mu \times 99-213\mu$.

Measurements:

Perithallial cells ..	.. $7.8-9.1-10.4\mu \times 7.8-10.4\mu$.
Medullary hypothallial cells ..	bigger, $18.2-26-31\mu \times 10.4-13\mu$.
	smaller, $10.4-13\mu \times 7.8-9.1\mu$.
Conceptacles ..	.. $99\mu \times 99-213\mu$.

Description:

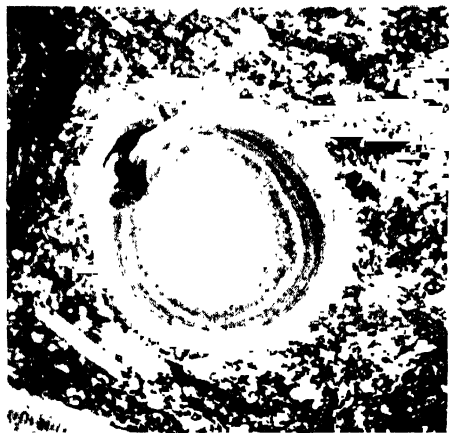
Fragments belonging to this species are crustaceous and branched. The specimens with crusts (Pl. XV, fig. 5) show a zonated perithallium of generally squarish-rectangular cells (mostly $9.1\mu \times 9.1\mu$) while the medullary hypothallial cells arranged in concentric rows show dark streaks (under low magnification) composed of cells of smaller dimensions (under high magnification). The horizontal walls of the medullary hypothallial cells are continued with each other (Pl. XIV, figs. 4 and 5; Pl. XV, fig. 6). Fragments exhibiting the aspect of crusts have ill preserved hypothallium, with a clear lattice of perithallial cells. The number of perforations in the roof of the conceptacles is not known.

Comparisons:

This species shows some similarity with *M. lakiense* in the size of the perithallial cells but is distinguished clearly by the hypothallial characters and the shape and measurements of the conceptacles. *M. punjabense* also differs in possessing a medullary hypothallium which shows a row of smaller cells in the region of zonation. The concentric rows do not show the zig-zagging present in *M. lakiense*. The medullary hypothallial tissue also shows the presence of cells of smaller size adjoining the lines of growth which are represented as dark streaks under low magnification. Also the conceptacular dimensions distinguish it from the associated species *M. lakiense*.

The present form is closer to *M. tropicale* Lemoine (1934, p. 277) in having the region of medullary zonation composed of smaller cells. In the present form the darker zones under high magnification are seen to be made up of one or rarely two rows of smaller cells $10.4-13\mu \times 7.8-9.1\mu$. This change in the size of the cells is gradual. There are two to three rows of cells preceding and succeeding the region of zonation, which are a little smaller than the usual size of the medullary hypothallial cells.

M. tropicale is known only as thin branches. It possesses rows of smaller cells in the dark zone preceding the lines of growth. *M. punjabense* differs in having a few rows of smaller cells preceding and succeeding the line of growth which is composed of the smallest cells and also by the size of the cells forming the medullary tissue. In *M. tropicale* Lem. the size of the rows forming the medullary hypothallium being $20-40\mu$, mostly $30-35\mu$ high and $5-15\mu$ broad attaining even 20μ , while the smaller cells are $11-15\mu$ high. Lemoine (1934, p. 277) in the description of this species has not indicated the presence or absence of the conceptacles. Although the similarity in showing a tendency to develop smaller cells in the growth zones of the medullary hypothallium offers a good reason to identify these fragments with *M. tropicale*, a direct assignment to it cannot be made without knowing the size and shape of the conceptacles in *M. tropicale*. Hence these fragments are treated as belonging to a new form.



1



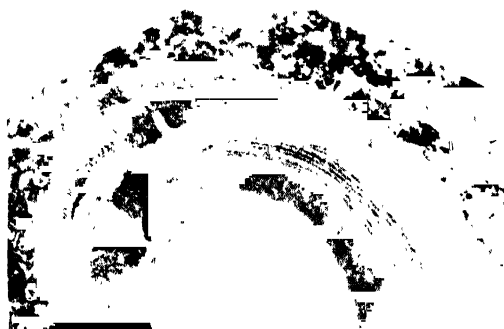
4



2



5



3



6

Mesophyllum (?) sp. indet.

(Pl. XV, figs. 1, 2, 3 and 4).

Diagnosis:

Thallus observed as branches. Perithallium zoned into cells of two dimensions. The bigger cells adjoining the hypothallial zone and the smaller occupying the outer part. In a vertical section the conceptacles appear to be plano-convex in shape. Number of openings not known.

Measurements:

Perithallial cells ..	.. bigger, $10.4-20.8\mu \times 7.8-10.4\mu$. smaller, $5.2-13\mu \times 7.8-10.4\mu$. (vertically or horizontally flattened).
Medullary hypothallial cells ..	.. $13-18.2\mu \times 7.8-13\mu$.
Conceptacles ..	.. $104\mu \times 200\mu$.

Description:

The species is represented by fragments of branches 1.5-2.2 mm. thick which have been classed together because all have a zone of small cells alternating with a zone of big cells (Pl. XV, figs. 1 and 3), the latter adjoining the medullary hypothallial zone. There is a single section showing a part of the branch cut obliquely (Pl. XV, fig. 4) with a conceptacle. The number of pores in the roof of the conceptacle could not be made out. The presence of zonation in the perithallial region with a conceptacle (Pl. XV, fig. 4) indicates that it belongs to *Mesophyllum*. The two photos (Pl. XV, figs. 1 and 2) represent serial sections of the rock which indicate that the form possessed furcate branches. A transverse section (Pl. XV, figs. 1 and 3) shows the presence of a secondary hypothallium in these forms. The presence of a secondary hypothallium is common in *Archaeolithothamnium*. Secondary hypothallium is known in *A. lugeoni*. In *A. digitatum* Pfender and *A. affine* Howe a zoned medullary hypothallium and perithallium is noticed and I suspected the fragments present in my slides to represent *Archaeolithothamnium*. But the discovery of one transverse section (Pl. XV, fig. 4) with a conceptacle in the perithallium showing bigger and smaller cells, most probably belonging to these forms, indicates it to be otherwise. In that case only *Lithophyllum* and *Mesophyllum* are to be considered and it appears to be a *Mesophyllum* because of the presence of zonation in the perithallial tissue of the branches.

Comparisons:

The fragments described here as *M.* (?) sp. show some similarities with *A. digitatum* Pfender (1926, pp. 24-25) from the Santonien of Basse-Provence and *A. affine* Howe (1919, pp. 11-12) in possessing perithallial cells of different sizes. *A. digitatum* has been described to possess zones of growth in the medullary hypothallium and in the perithallial tissue.

A. digitatum is also described by Lemoine (1939, pp. 44-45) from upper Turonien. Lemoine has also sketched (1939, p. 49, fig. 6) a fragment of a branch indicating a zoned medullary hypothallium with typical sporangia at the sides, which but for these could easily have been mistaken for a *Mesophyllum*. No such fragment with *Archaeolithothamnium* type of sporangia could be observed. On the contrary a cross-section (Pl. XV, fig. 4) showed the presence of a conceptacle which indicates these fragments to be either *Lithophyllum* or *Mesophyllum*.

Before assigning it to one of the two genera *Lithophyllum* and *Mesophyllum* we have to consider the number of pores present in the roof and also the presence and

absence of zonation in the vegetative tissue. The single fragment with a conceptacle does not show the number of pores in the roof but the presence of zonation indicates it to be a *Mesophyllum*.

Among the *Mesophyllum* it shows some similarity with *M. Koritzae* Lem., *M. varians* Lem. and *M. Pfenderae* Lem. The former is a crustaceous species without branches while the fragments now described fall in the 2nd section and 2nd group of the classification table for the genus (Lemoine, 1939, p. 80) showing the presence of ramified branches.

With *M. varians* it resembles in its cell dimensions which shows nearly the same range of variation among the bigger and smaller cells: 4–12 μ long in *M. varians* at the upper part of the zone. But Lemoine's descriptions (1934, p. 276 and 1939, pp. 86–87) give no indication of the presence of the conceptacles in *M. varians*. Because of the lack of better specimens the Laki form has been dealt with as a *Mesophyllum* (?) sp. indet.

SUMMARY.

A comparison of the diagnostic features of *Lithothamnium*, *Mesophyllum* and *Lithophyllum* is given. The status of *Mesophyllum* as a distinct genus is discussed. Previous records of this genus in India are noted and two new species have been described and figured from the Eocene of the Salt Range.

ACKNOWLEDGEMENT.

I am grateful to Professor S. R. N. Rao for the material, guidance and many helpful suggestions.

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PLATE XIV.

Mesophyllum.

- FIG. 1. *Mesophyllum lakiense* sp. nov. A vertical section through a thin crust, showing the perithallium with two conceptacles and the basilar hypothallium. $\times 67$.
2. *M. lakiense* sp. nov. A longitudinal section through a branch showing a much zig-zagging aspect of the medullary hypothallial cells. The perithallium is badly preserved. $\times 67$.

- Fig. 3. *M. lakiense* sp. nov. An obliquely vertical section passing through a crust showing a number of conceptacles and a part of the basilar hypothallial cells cut cross-wise. $\times 67$.
- „ 4. *M. punjabense* sp. nov. A longitudinal section through a branch showing a zonated medullary hypothallium. The darker zones are of comparatively smaller cells. $\times 37$.
- „ 5. *M. punjabense* sp. nov. A part of fig. 4 enlarged to show the darker band with a single row of small cells. On either side of it are noticed cells which gradually increase in length to those of the medullary tissue cells. $\times 160$.
- „ 6. *M. lakiense* sp. nov. A cross-section passing through a region of bifurcation. The perithallium shows many conceptacles typical of this species. $\times 16$.

PLATE XV.

Mesophyllum.

- Fig. 1. *Mesophyllum* (?) sp. A cross-section through a branch showing a part of the medullary hypothallium, the perithallium with a zone of bigger and smaller cells. Recurrent hypothallium is also observed. $\times 23$.
- „ 2. *M.* (?) sp. A very oblique cross-section passing through the zone of bifurcation situated a little above the part shown in photo 1. Photos 1 and 2 represent two sections cut serially. $\times 23$.
- „ 3. *M.* (?) sp. A part of the photograph No. 1 enlarged to show the details. $\times 37$.
- „ 4. *M.* (?) sp. Part of a cross-section through a branch showing the medullary hypothallial cells cut transversely, the perithallium with a zone of bigger and smaller cells, the latter indicating the presence of a conceptacle. $\times 37$.
- „ 5. *M. punjabense* sp. nov. A vertical section passing through a crust showing the basilar hypothallium and a number of laterally ovoid conceptacles in the perithallium. $\times 48$.
- „ 6. *M. punjabense* sp. nov. A longitudinal section through a branch (nodule ?) showing the medullary hypothallium with a row of smaller cells in the zones of growth (the two lines of growth near the top show it better) and two laterally elongated conceptacles in the zonated perithallium. $\times 37$.

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NOTE ON THE LENGTH OF HIGH-VELOCITY 'MUNROE' JETS

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(Communicated by Dr. D. S. Kothari, F.N.I.)

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1. INTRODUCTION.

The study of the properties of high-velocity jets resulting from the base detonation of 'Shaped-Charges' fitted with 'liners' has received considerable attention in the last few years. In two fundamental papers on 'Shaped-Charges' Birkhoff *et al.* (1948) and Pugh *et al.* (1952) presented hydrodynamic theories of jet formation and target penetration. The latter authors have shown that when a detonation wave sweeps from apex to base along a conical liner, it collapses and forms a jet having a uniform distribution of mass and a linear gradient of velocity. The velocity of the head of jet is approximately 5 to 10 times that of a .303 rifle bullet. According to the theory, for a given target the depth of penetration by a jet is independent of the velocity of jet and depends upon its length and effective density. Eichelberger *et al.* (1952) have discussed a graphical method for tracing the development of the jet, but no explicit mathematical expression for the length of jet has been given. In this note such an explicit expression for the length of jet is derived.

2. LENGTH OF JET ON STEADY-STATE HYDRODYNAMIC THEORY

In the steady state theory, it was assumed that the velocity of collapse V_0 was constant from apex to base of liner and angle β , which the collapsing liner made with the axis, was also constant. From elementary consideration it can be shown that when a jet is completely formed, length of the jet is equal to the slant length of the conical liner, i.e. $\frac{1}{2} D \operatorname{cosec} \alpha$ where D is the outside diameter of the conical liner and 2α the original angle of the conical liner. During collapse the jet and the slug will have exactly the same length. The formation of jet is complete when the head of jet is at a distance, i.e.

$$\frac{D}{2} \left[\tan \frac{\alpha + \beta}{2} + \operatorname{cosec} \alpha \right]$$

beyond the cone base.

The steady state hydrodynamic theory does not explain certain experimental observations, e.g. the velocity gradient in the jet, 'after-jet' effect and the dependence of penetration on standoff. The length of jet calculated on the basis of this theory is $\frac{1}{2}$ to $\frac{1}{4}$ the actual penetration.

3. LENGTH OF JET ON PUGH *ET AL.*'S EXTENSION OF HYDRODYNAMIC THEORY.

Pugh *et al.* have assumed that V_0 decreases continuously from apex to base. It decreases gradually near the apex but falls much more rapidly near the base. This change in V_0 results in increase of angle β from apex to base of liner. The decreasing V_0 and increasing β from apex to base of conical liner produce in the jet a uniform distribution of mass and a linear distribution of velocity.

APB is the upper half of the original conical liner (Fig. 1) having 2α its original angle, D the outside diameter of the liner and AQN is the axis of the liner. When

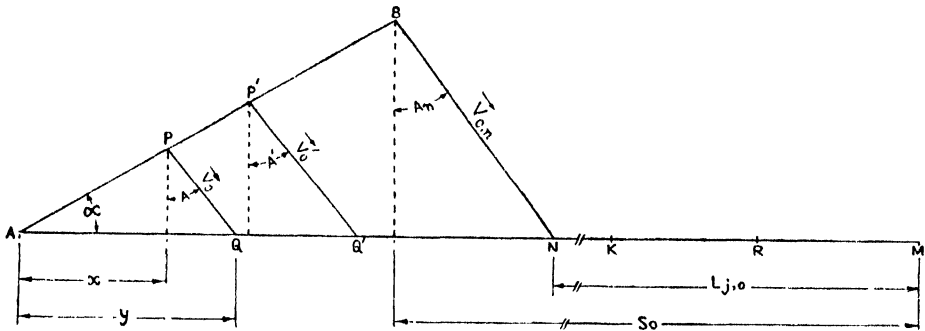


FIG. 1. APB is the upper half and AQN is the axis of the original conical liner. When a detonation wave sweeps from apex to base along the conical liner APB , the elements P , P' and B move towards the axis with velocities V_0 , V_0' and $V_{0,n}$; make angles A , A' and A_n with the perpendicular to the axis AQN ; reach the axis at times t , t' and t_n ; and the mass dm_j of each element travels to the right with velocities V_j , V_j' and $V_{j,n}$ respectively. RK represents the length of the jet at the time t_n arising from any finite element PP' in the original conical liner. (The thickness of metal liner and the diameter of jet are not shown in the figure.)

a plane detonation wave travelling parallel to its axis reaches P , the liner element at P collapses and moves along a line that makes an angle δ with the normal to the surface. The liner element moves towards the axis with a velocity V_0 , which remains constant until the axis is reached. The position of P in the parent cone is fixed by a length x measured from the apex along the axis to the plane of the zonal element P . After collapsing the element P reaches the axis at Q and the position of Q is fixed by a length y measured from the apex along the axis. Let T represent the time ($T = x/U_d$) the detonation wave takes in travelling from the apex to the liner element P , and $t - T$ the time element P takes to travel to Q . Then

$$t = x \left[\frac{\tan \alpha \sec A}{V_0} + \frac{1}{U_d} \right] \quad \dots \quad (1)$$

$$y = x (1 + \tan \alpha \tan A) \quad \dots \quad (2)$$

where $A = \alpha + \delta$ and U_d is the velocity of detonation of the explosive and is independent of x . When the detonation wave reaches the base of the liner, the element at B starts to collapse, and the jet is fully formed when B reaches the axis at N . Let t_n represent the time for the detonation wave to travel from the apex to the base of the liner plus the time for the element at the base of the liner to reach the axis, then

$$t_n = \frac{D}{2} \cot \alpha \left[\frac{\tan \alpha \sec A_n}{V_{0,n}} + \frac{1}{U_d} \right] \quad \dots \quad (3)$$

where $V_{0,n}$ is the velocity with which the element B moves towards the axis and makes an angle δ_n with the normal to the liner surface and $A_n = \alpha + \delta_n$. The element P on reaching the axis divides into two elements of masses dm_s and dm_j which proceed along the axis at constant velocities V_s and V_j respectively. The element dm_j at time t is at Q . After a time t_n , it travels a distance $V_j (t_n - t)$ and is represented by an element R . Hence $AR = y + V_j (t_n - t)$.

Similarly another small element P' , collapses and after a time t_n let its position be represented by element K . Let V_0' , A' , y' , V_j' , etc. of element P' have the

same significance as V_0 , A , y , V_j , etc., for the element P . Hence $AK = y' + V_j(t_n - t')$. Let RK represent the length of jet at the time t_n arising from any finite element PP' . Hence

$$\begin{aligned}
 RK &= t_n(V_j - V_j') + (y - tV_j) - (y' - t'V_j') \\
 &= \frac{D}{2} \left[\frac{\sec A_n}{V_{0,n}} + \frac{\cot \alpha}{U_d} \right] (V_j - V_j') \\
 &+ x \left[1 + \tan \alpha \tan A - \frac{V_j \tan \alpha \sec A}{V_0} - \frac{V_j}{U_d} \right] \\
 &- x' \left[1 + \tan \alpha \tan A' - \frac{V_j' \tan \alpha \sec A'}{V_{0'}} - \frac{V_j'}{U_d} \right] \quad \dots \quad (4)
 \end{aligned}$$

If the element PP' is taken such that P approaches the apex of the liner and P' approaches the base of the liner, then the element PP' refers to slant length of the liner, i.e. $\frac{1}{2} D \operatorname{cosec} \alpha$, and $x \rightarrow 0$ and $x' \rightarrow \frac{D}{2} \cot \alpha$. The Eq. (4) reduces to

$$L_{j,0} = \frac{D}{2} \left[V_{j,1} \left(\frac{\sec A_n}{V_{0,n}} + \frac{\cot \alpha}{U_d} \right) - \cot \alpha - \tan A_n \right] \quad \dots \quad (5)$$

where $V_{0,1}$, δ_1 , β_1 , $V_{j,1}$, etc., for the element from the apex of liner have the same significance as V_0 , δ , β , V_j , etc., for the element P and $L_{j,0}$ is the length of complete jet at the time t_n . Pugh *et al.* have given the following relations for V_j and V_0

$$V_j = V_0 \operatorname{cosec} \frac{\beta}{2} \cos \left(\alpha + \delta - \frac{\beta}{2} \right)$$

$$V_0 = 2 U_d \sec \alpha \sin \delta$$

Substituting the values of $V_{j,1}$ and $V_{0,n}$, the Eq. (5) reduces to

$$\begin{aligned}
 L_{j,0} &= \frac{D}{2} \left[\sin \delta_1 \operatorname{cosec} \frac{\beta_1}{2} \cos \left(\alpha + \delta_1 - \frac{\beta_1}{2} \right) \left\{ \sec A_n \operatorname{cosec} \delta_n + 2 \operatorname{cosec} \alpha \right\} \right. \\
 &\quad \left. - \cot \alpha - \tan A_n \right] \quad \dots \quad (6)
 \end{aligned}$$

From the collapse process it is evident that the formation of a jet is complete when the head of jet is at a distance S_0 where $S_0 = L_{j,0} + \frac{D}{2} \tan A_n$ from the base of the liner.

The length of jet $L_{j,1}$ at any standoff S_1 (distance of the front face of target from the base of conical liner) is given by the expression

$$L_{j,1} = L_{j,0} + \frac{S_1 - S_0}{V_{j,1}} (V_{j,1} - V_{j,2}) \quad \dots \quad (7)$$

where $V_{j,1}$ and $V_{j,2}$ are the velocities of the head and the tail of the jet respectively.

4. ACKNOWLEDGEMENTS.

The author is indebted to Dr. D. S. Kothari, Scientific Adviser to the Ministry of Defence, for encouragement and interest in this work. He also wishes to thank Dr. V. R. Thiruvankatachar for helpful discussions.

ABSTRACT.

In two papers Birkhoff *et al.* (1948) and Pugh *et al.* (1952) presented hydrodynamic theories of jet formation and target penetration by explosives with lined conical cavities. Penetration has been shown to depend on jet characteristics, i.e. its length and effective density. In this note an explicit expression for the length of jet is given.

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THE RÔLE OF INITIAL PARENCHYMA IN THE TRANSFORMATION OF THE STRUCTURE DIFFUSE-POROUS TO RING-POROUS IN THE SECONDARY XYLEM OF THE GENUS *Gmelina* LINN.

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1. INTRODUCTION.

The genus *Gmelina* of the *Verbenaceae* is confined to the Indo-Malayan region, South China, Philippine Islands, New Guinea, Australia, Solomon Islands and New Caledonia. It contains about 35 species, of which 10 are found in New Guinea and in the Islands round about it. The genus is mostly woody and produces well known timbers of trade, for example 'Gamari' of India and 'White beech' of Australia. It grows from sea-level up to 5,000 feet elevation but is nowhere gregarious.

Owing to its commercial importance, the wood of *G. arborea* Roxb. has been studied by some workers. Gamble (1922) is of the opinion that its growth ring is marked 'either by a white line or numerous pores in its spring wood'. Pearson and Brown (1932) report that the wood is 'more or less ring-porous'. Again, Ghosh (1943) and Chowdhury (1945) describe the timber as 'diffuse-porous to semi-ring-porous'. A difference of opinion as to whether the timber is ring-porous or diffuse-porous is, therefore, evident. The reason for this was not clear till recently when I (1947) came across in this timber not only diffuse-porous and ring-porous structure but also the intermediate stages between the two extremes. The majority of the specimens, I have examined, are diffuse-porous and some of them give the impression that they have initial parenchyma cells like *Terminalia tomentosa* W. & A. (Chowdhury, 1934, 1936), *Salix matsudana* Koidz. (Chang, 1936), *Dalbergia sissoo* Roxb. (Chowdhury, 1940a), *Swietenia macrophylla* King (Chowdhury, 1940b) and *Entandrophragma macrophyllum* A. Chev. (Hummel, 1946). The remaining specimens show semi-ring-porous to ring-porous structure.

In view of some similarity between the initial parenchyma cells of diffuse-porous woods and the parenchyma cells that occur in the early wood of ring-porous woods (Chowdhury, 1936) I anticipated that an intensive study of the secondary xylem of the genus *Gmelina* might throw some light on the rôle that the initial parenchyma cells play in the transformation of its structure from diffuse-porous to ring-porous. A complete picture has now been obtained; the name initial parenchyma cell appears to be applicable to all ring-porous woods and to some diffuse-porous woods.

It may be pointed out that my previous observation (1947) on the presence of initial parenchyma cells in the diffuse-porous wood of *Gmelina arborea* Roxb. was based on the examination of wood samples in the laboratory. It required confirmation in the secondary xylem of growing trees. This has now been done and is reported in the first part of the paper.

The part played by the initial parenchyma cells raises some general questions on morphology, physiology and taxonomy. These are discussed briefly.

2. MATERIAL AND METHODS.

For examination of the secondary xylem in growing trees, two localities were selected. One was at Dehra Dun, Uttar Pradesh, and the other at Manoharpur, Bihar. At each locality two mature trees were studied.

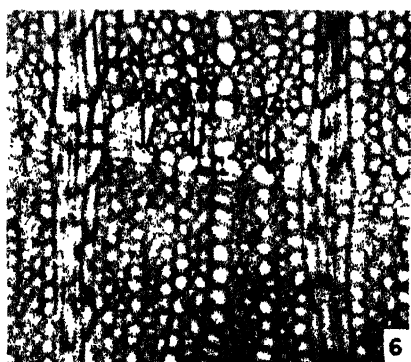
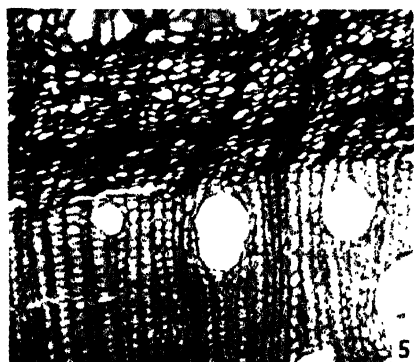
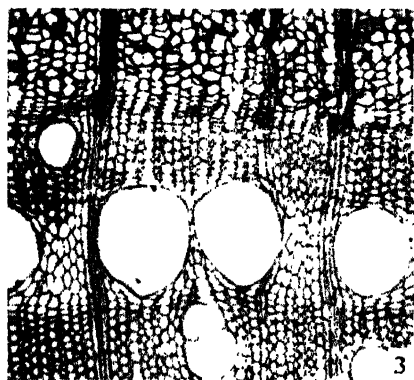
Two methods can be applied for the determination of the actual position of the concentric parenchyma cells that delimit the growth rings in diffuse-porous woods. One method is to collect small blocks, containing inner phloem, cambium and xylem, and find out by microscopic examination the formation and maturation of the first and the last tissues that are produced in a growth season. The exact position of the concentric parenchyma cells either as initial or terminal is thus established. The other method is short and involves collecting only 1 or 2 similar blocks during the normal dormancy of the cambium, say from November to February. The concentric parenchyma cells are taken as terminal or initial depending on whether the last tissues formed during a growth season are parenchyma cells or fibres.

Altogether 75 specimens of the secondary xylem were studied. They represent 12 species. The countries from which they come are given in Table I. 10–12 microns thick cross, tangential and radial sections were cut. Staining of these sections requires careful attention. I have found Haidenhains' iron-alum haematoxylin and safranin most satisfactory. The parenchyma cells take a distinctly dark stain in contrast with the fibres which are light red. There is no difficulty in

TABLE I.

Showing the country of origin and the number of specimens studied.

Serial No.	Name of species.	Country.	Number of specimens.
1	<i>G. arborea</i> Roxb.	India	28
		Burma	4
		Ceylon	1
		Siam	1
2	<i>G. asiatica</i> Linn.	India	2
3	<i>G. hystrix</i> Schult. ex Kurz	India	2
4	<i>G. villosa</i> Roxb.	India	3
		Java	1
		Sumatra	1
		Malaya	1
5	<i>G. fasciculiflora</i> Benth	Australia	2
6	<i>G. hainanensis</i> Oliver	China	1
7	<i>G. leichardtii</i> Muell. ex Benth.	Australia	15
8	<i>G. macrophylla</i> Benth.	Australia	2
		New Guinea	3
		Java	1
9	<i>G. moluccana</i> Backer ex Heyne	New Guinea	2
		Formosa	1
10	<i>G. palawensis</i> Lam	Solomon Islands	2
11	<i>G. solomonensis</i> Bakh	New Guinea	2
12	<i>G. sessilis</i> White and Francis		
Total			75



distinguishing the initial parenchyma cells from the thin walled early fibres. The single stain of safranin has been found unsatisfactory for this study. Sections stained by this method do not bring out a clear difference between fibres and parenchyma cells. Mostly the cross-sections have been carefully examined. Tangential and radial sections have been studied only when the cross-sections create some confusion about the distribution of the vertical parenchyma cells.

3. RESULTS.

(a) *Study of the xylem in growing trees of G. arborea Roxb.*

For the materials from the trees at Dehra Dun, the long method was used during 1947 and 1948. The first tissues in the xylem of 1947 were parenchyma cells and the last tissues fibres (Pl. XVI, Fig. 4). These observations were confirmed in 1948. The position of the concentric parenchyma cells in the growth ring has, therefore, been established as initial.

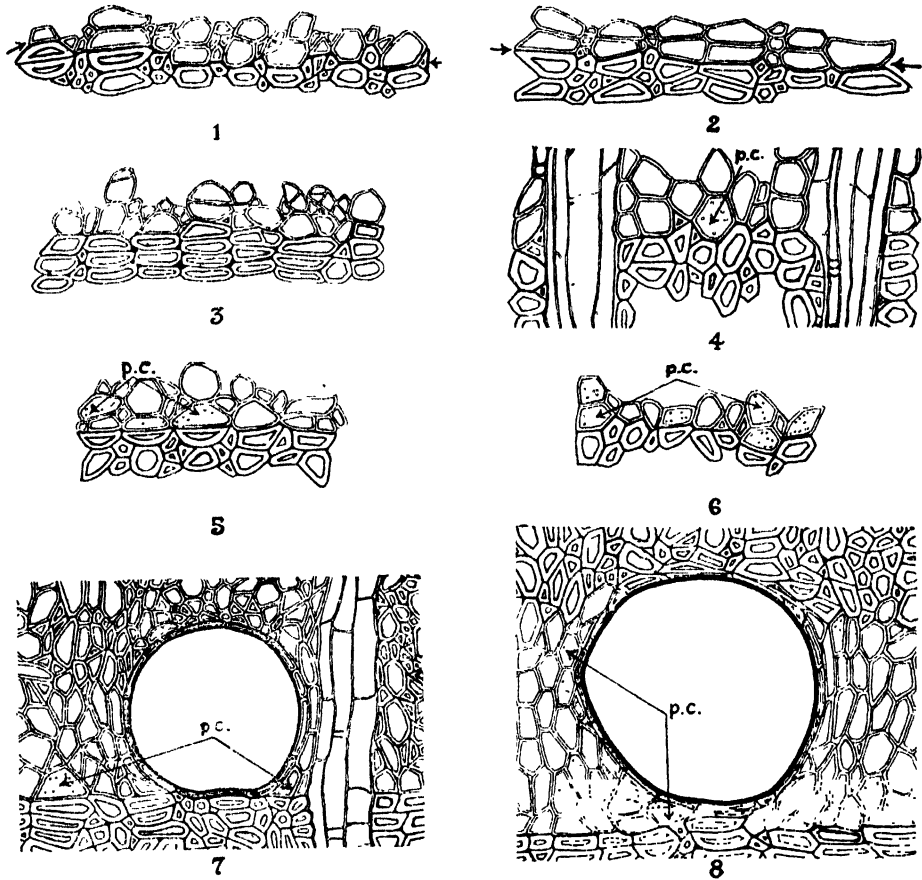
For the material from Manoharpur the short method was applied. Small blocks were collected in February, 1948 and 1949. The last tissues of the xylem formed in the year 1947 and 1948 were found to be fibres (Pl. XVI, Figs. 3, 5), thus confirming the observations made at Dehra Dun.

(b) *Study of porousness in the genus Gmelina Linn.*

34 wood samples of *G. arborea* Roxb. have been studied.* All show well marked growth rings on their end surfaces (Pl. XVI, Figs. 1, 2) and only 6 contain ring-porous structure. Amongst these 6 samples, not a single one shows ring-porous structure throughout; in each specimen only 1-2 growth layers exhibit ring-porousness and the remaining growth layers are diffuse-porous (Pl. XVI, Fig. 2). Microscopic examination of the various diffuse-porous growth layers shows a great variation in their anatomical structure. The size, wall-thickness and shape of fibres of early wood and late wood, at the junction of the growth layers, play a leading part in bringing about the demarcation of the growth rings (Text-figs. 1, 2). The extreme late fibres are often tangentially flattened, showing up conspicuously against the triangular to rectangular early fibres (Text-fig. 3). When the initial parenchyma cells make their appearance for the first time, they are, for the most part, scattered singly, and may not be easy to detect. This is owing to the fact that the early fibres and the initial parenchyma cells do not always show a great difference in their wall thickness. But detection of the parenchyma cells is not so difficult because of the prominent pits that are found on their end walls (Pl. XVI, Fig. 6; Text-figs. 4, 5). The next stage towards ring-porosity shows a single but discontinuous row of initial parenchyma cells abutting on the extreme late fibres of the previous year (Text-fig. 5). This distribution may change into a continuous layer of 2-3 parenchyma cells (Text-fig. 6) especially when they come in contact with early vessels. Here the vessels may or may not be completely surrounded by parenchyma cells. At this stage the timber may show diffuse-porous or semi-ring-porous structure depending on whether the initial parenchyma cells are scanty or abundant (Pl. XVII, Fig. 7, Text-fig. 7). Lastly, when the vessels of the early wood are almost completely embedded in the initial parenchyma cells, a true ring-porous structure is produced (Pl. XVII, Fig. 8, Text-fig. 8).

Amongst the remaining species, the growth rings are clearly visible in *G. asiatica* Linn., *G. fasciculiflora* Benth. and *G. palawensis* Lam, although no initial parenchyma cells are present in them. The demarcation of growth rings is owing to the difference in wall thickness of early and late fibres. The growth rings are rather faintly marked in *G. moluccana* Backer ex Heyne (Pl. XVII, Fig. 10), *G. solomonensis* Bakh and *G. sessilis* White and Francis, but they show scattered parenchyma cells in their early wood. In *G. hystrix* Schult ex Kurz, *G. macrosphylla*

Benth. and *G. villosa* Roxb. the wood structure varies from diffuse-porous to ring-porous depending on whether the initial parenchyma cells are scanty or fairly abundant or abundant. The secondary xylem of *G. leichardtii* Muell. ex Benth. shows, as a rule, a diffuse-porous structure. The demarcation of growth ring is owing to the difference in the shape of the cells and thickness of their walls. Initial



TEXT-FIGS. 1-8. *Gmelina arborea* Roxb. (Camera lucida drawings of cross-sections at the junction of growth layers.)

FIG. 1. Specimen No. 2303 from Kamrup, Assam, showing difference in shape and wall thickness of fibres. FIG. 2. Specimen No. 7283 from Sadiya, Assam, showing difference in wall thickness only. FIG. 3. From the same specimen, note radially flattened late fibres and normally shaped early fibres. FIG. 4. Specimen No. 7494 from Wynaad, Madras, showing the first appearance of initial parenchyma (p.c.). FIG. 5. Specimen No. 7311 from Nowgong, Assam, showing discontinuous single row of initial parenchyma. FIG. 6. Specimen No. 1390 from Chittagong Hills, Bengal, showing more than one row of initial parenchyma. FIG. 7. Specimen No. 7311 from Nowgong, Assam, showing semi-ring-porous structure with a few parenchyma cells. FIG. 8. From the same specimen showing a true ring porous structure with well developed parenchyma cells. ($\times 80$).

parenchyma cells when present are rather scanty. Occasionally this timber also shows a concentric row of parenchyma cells at regular intervals, a type of structure that recalls that of some members of the family *Rutaceae*. Rows of tangentially flattened cells at regular intervals exhibit simple pits on their end walls indicating their parenchymatous nature (Pl. XVII, Figs. 9, 11). Lastly, *G. hainanensis* Oliver

exhibits semi-ring-porous to ring-porous structure. The initial parenchyma cells are well developed. Of the various species of *Gmelina*, this shows the most pronounced ring-porous structure. However, it should be pointed out that only one specimen was examined by me. Whether or not a true ring-porous structure is a constant feature of this timber, it is not possible to say at present.

4. DISCUSSION.

(a) *Morphological aspect.*

The dicotyledonous woods are classified into two groups: the diffuse-porous and ring-porous. The main criteria for the classification are the distribution of the vessels and the variation in their sizes. In the diffuse-porous woods, the vessels are more or less evenly distributed and their size varies little or only gradually from the inner to the outer portion of the growth layer. On the other hand, in the ring-porous woods, the vessels in the inner portion of the growth layer are large and form a ring in contrast with those of the outer portion where they are small in size and are distributed in an even manner. In addition to these two groups, some workers (Brown and Panshin, 1949; Chowdhury, 1945; Ghosh, 1943) have come across intermediate types and have called them semi-ring-porous or semi-diffuse-porous. In these classifications little attention has been paid to the initial parenchyma cells which now seem to play an important part in the formation of the ring-porous structure. A comparative study of the different criteria shows that it is the parenchyma cells which set the beginning of the transformation of diffuse-porous wood into ring-porous wood. Their first appearance in the diffuse-porous group is hardly noticeable because they are scanty and are distributed singly amongst the early fibres of the growth ring. Seldom are they detected till they come in contact with some of the vessels in the inner portion of the growth layer. It will, therefore, be seen that the distribution of the vessels is the next important criterion in this transformation. When the early vessels are much larger than the late vessels the process of transformation is complete. So far I have dealt with the anatomical structure of growth rings of normal width. When transformation takes place in a narrow growth ring, the structure is rather interesting. Most of the early vessels are then in contact with the concentric bands of initial parenchyma cells and the late vessels are either scanty or not developed at all. The general picture is, therefore, of the type of semi-ring-porous or semi-diffuse-porous wood in which the parenchyma cells are developed fairly well.

In a previous paper (Chowdhury, 1936) the advisability of using the term initial parenchyma cell to the ring-porous woods was discussed. No decision at that time could be arrived at owing to lack of sufficient data. The present study has provided a complete picture of the transformation and there now appears to be no objection to apply the term initial parenchyma to all ring-porous and to some diffuse-porous woods.

The growth rings are always visible in the ring-porous woods, but amongst the diffuse-porous woods, some show growth rings and others do not. The relation between the initial parenchyma cells and the growth rings is now clearly understood. It can be said that the growth rings can be determined without difficulty in such diffuse-porous woods as have initial parenchyma cells.

(b) *Physiological aspect.*

Ring-porous trees are mostly confined to the countries of temperate climate. This has led to the generalization that the rigour of growth conditions prevalent in temperate climate is responsible for the production of ring-porousness. In elaborating this theory Bailey (1924) says, 'The typical ring-porous condition arises

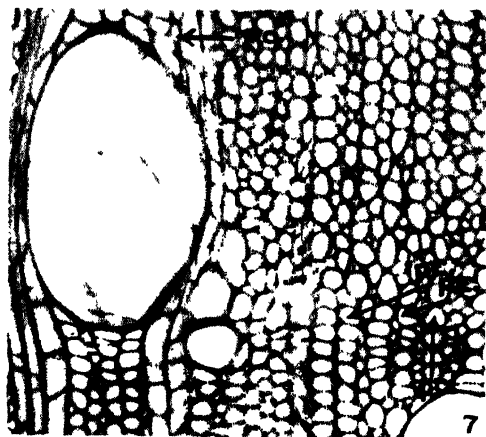
apparently when plants which have undergone characteristic structural modifications in certain tropical or sub-tropical environments are subjected to cold winters or alternating very dry and wet seasons. In other words, this is closely associated with a pronounced resting period and the commencement of deciduous habit. It is significant that certain species of a widely dispersed genus may be ring-porous and others diffuse-porous, depending on their phytogeographical distribution'. Metcalfe and Chalk (1950) have also supported this view. Haberlandt (1928) is of opinion that the conduction of sap is the first requirement during the early part of the growth season. The formation of a pore-zone at this period is, therefore, a physiological necessity. Later on the mechanical strength has to be given preference over conduction. The late wood is therefore dense with evenly distributed vessels. Forsaith (1920) has provided some additional data in support of this by studying some American trees. He has found some species of *Betula* and *Alnus* which are normally diffuse porous trees, showing ring-porous structure when grown in localities with alpine climate. Furthermore, Huber's (1935) determination of the rate of conduction of sap in the diffuse-porous and ring-porous trees has given added weightage to this theory.

On the other hand, the evidence from tropical countries is different. Firstly, there are some ring-porous trees which are exclusively confined to the countries of tropical climate, e.g. *Teciona grandis* Linn. f. (Chowdhury, 1940b). Secondly, some species like *G. arborea* Roxb. which grow from the sea-level to the high hills of India, do not show any direct effect of the local climate. I have studied wood samples of this species collected from the hot and moist plains of India and they often show ring-porousness in their growth layers. Furthermore, the trees growing under semi-temperate to temperate climate on the hill forest of 4-5,000 ft. elevation above sea-level, do not always exhibit ring-porous structure. Thirdly, the assumption that the tropical trees have radial growth throughout the year has not been confirmed. Researches carried out at different parts of India have shown that most trees, diffuse-porous or ring-porous, have cambial activity for only a few months in the year and all of them show a distinct rest period. Moreover, Hummel's (1946) work has shown that the African trees behave exactly in the same way as the Indian trees do.

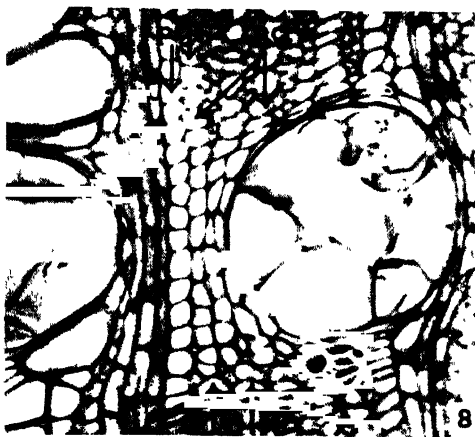
In summing the available data from temperate and tropical countries, it would appear that both localities have an active and a dormant period; the duration of cambial activity may, however, vary. The ring-porous trees are found in a greater number in temperate climate than in tropical climate. Some normally diffuse-porous trees under adverse conditions turn into ring-porous trees while others remain diffuse-porous. Here it should be emphasized that the number of dicotyledonous trees that has been investigated for understanding the physiological aspect of their ring-porousness, is still very small. An intensive study of a large number of diffuse-porous and ring-porous trees from both temperate and tropical countries, is indicated. Interesting results may also be expected from a comparative study of species that have been grown under markedly different climatic conditions.

(c) *Taxonomic and other aspects.*

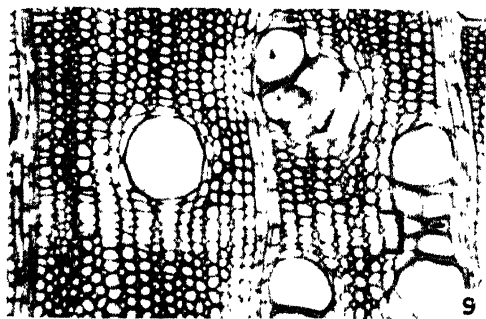
The secondary xylem of the genus *Gmelina* has a remarkably uniform gross-structure. All the species studied show much the same anatomy except possibly *G. hainanensis* Oliver. This means that different taxonomic species cannot be differentiated by anatomical method. However, *Gmelina* is not an exception in this respect; many other genera are known to have a similar tendency (Metcalfe and Chalk, 1950; Chowdhury, 1948). Another point to note in this genus is that evolution has proceeded at different rates in different organs. The exomorphic characters have advanced far ahead of the anatomical characters. That all the



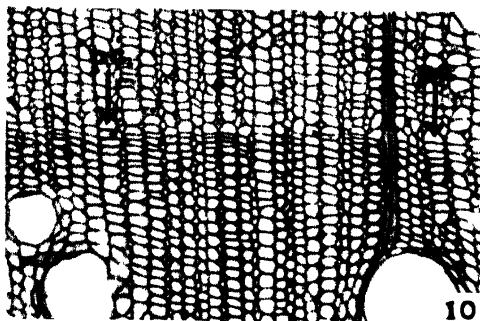
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parts or tissues of an organism do not show a synchronized evolution, is often lost sight of, causing considerable confusion in our understanding of the classification and the phylogeny of the Dicotyledons (Bailey, 1951).

Apart from these considerations, the variation in the minute anatomical structure of *Gmelina* raises some questions of fundamental importance. Firstly, it is not clear what controls the differentiation of the xylem mother cells after they are cut off from the cambium. When there is no initial parenchyma cell, the first row of early wood is made up of only fibres. The appearance of parenchyma cells amongst these fibres marks the onset of ring-porousness. What factors control the xylem cells to change over from the production of fibres to that of the parenchyma cells? How is it regulated in such a way that there is a gradual reduction in the number of the early fibres and a proportionate increase in the parenchyma cells till the gross structure is completely changed? The physiological factors are said to be responsible for this, but an analysis of the responses of plants to environmental conditions does not bear it out, for all trees do not respond in the same manner to the changes in environments. The only other factor that is at work here is genetical in origin. How that works is beyond the scope of this paper but all the available data lead to the conclusion that the variation in the anatomical structure of the secondary xylem of *Gmelina* is genetically controlled.

Secondly, ring-porous trees and diffuse-porous trees are well known groups; so are some intermediate types. But for the first time it has come to light that one and the same species not only produces ring-porous and diffuse-porous structure but also all the intermediates between the two extremes. As far as this tree is concerned, nature seems to have left nothing to chance. A similar observation has been recently made on the seeds of *Atriplex hortensis* Linn. by Salisbury (1952). Each individual plant 'produces two kinds of seeds that are totally unlike one another'. The question he raises are very important and I can do no better than quote from his paper. He says, 'These two types of seed both yield a high percentage of seedlings, but differ markedly in their rate of germination and, moreover, in their physiological resistance to adverse conditions They clearly, therefore, play different rôles in dispersal and survival. But it is not so much this aspect that I would here stress as the important question as to how two such different seeds have come to be evolved by one and the same species by orthodox views of natural selection, unless we assume the almost impossible coincidence that at each stage of their respective evolution they maintained a precise equality of survival value'.

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5. SUMMARY.

1. Secondary xylem of some *Gmelina arborea* Roxb. gives the impression that it is a diffuse-porous wood with initial parenchyma cells. This has been confirmed by investigation on living trees.

2. Since the wood of *Gmelina arborea* Roxb. shows both diffuse-porous and ring-porous structure, it has been anticipated that an intensive study of this species is likely to reveal the rôle that the initial parenchyma cells play in the transformation of the structure from one to the other. The results show that three factors are at work; they are in order of importance: initial parenchyma, distribution of vessels and size of vessels.

3. Investigation of many species of *Gmelina* has shown that in gross they all have uniform anatomical structure. In every species the initial parenchyma cells play a vital part in the transformation of the structure from diffuse-porous to ring-porous.

4. The term initial parenchyma cell is applicable to all ring-porous and to some diffuse-porous woods.

5. The presence of initial parenchyma cells makes the determination of growth ring easy.

6. Some diffuse-porous trees turn into ring-porous trees under adverse conditions while others show no changes.

7. Different taxonomic species of *Gmelina* cannot be differentiated by anatomical methods. Here the exomorphic characters have advanced far ahead of the anatomical characters.

8. There are indications that the anatomical structure of the secondary xylem of *Gmelina* is genetically controlled.

9. The evolution of two extreme types of wood structure in the same species is discussed in the light of natural selection.

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EXPLANATION OF PLATES.

(All are cross-sections).

PLATE XVI.

Gmelina arborea Roxb.

- FIG. 1. Slide No. A 2713 from Wynaad, Madras, showing general structure of secondary xylem. Note semi-ring-porous and ring-porous structure in the same tree. $\times 10$.
- „ 2. Slide No. F 793 from Ceylon showing xylem. Note diffuse-porous and ring-porous structure. $\times 10$.
- „ 3. Slide No. RIV 179 from tree I, Bihar, 27th February, 1948, showing fibres as the last tissues in the growth ring for 1947. $\times 60$.
- „ 4. Slide No. RIV 167 from tree I, U.P., 7th October, 1947, showing the last tissues formed in the growth season as fibres. $\times 60$.
- „ 5. Slide No. RIV 212 from tree I, Bihar, 7th February, 1949. Note the last tissues of the growth ring formed in 1948 are fibres. $\times 60$.
- „ 6. Slide No. A 2711 showing a junction of two growth rings. Note a few parenchyma cells (p.c.) amongst the early fibres. $\times 60$.

PLATE XVII.

- Fig. 7. Slide No. 1792, *G. arborea* Roxb. showing semi-ring-porous structure. Note rather scanty parenchyma cells. $\times 110$.
- „ 8. Slide No. 2711, *G. arborea* Roxb. showing ring-porous structure. Note the early vessel is completely surrounded by parenchyma cells. $\times 110$.
- „ 9. Slide No. F 794 of *G. leichardtii* Muell. ex Benth. Showing concentric rows of tangentially flattened parenchyma cells like some woods of *Rutaceae*. $\times 60$.
- „ 10. Slide F 788 of *G. moluccana* Backer ex Heyne. Note the difference in shape and wall thickness of late and early fibres; the parenchyma cells and early fibres are difficult to distinguish at this magnification. $\times 60$.
- „ 11. Portion of Fig. 9 between brackets showing prominent pits on the end walls of six parenchyma cells under higher magnification. $\times 900$.

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A TAXONOMIC REVISION OF THE GENUS *ASCARINA* FORST

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INTRODUCTION.

The genus *Ascarina* Forst. (with *A. polystachya*) was instituted in 1776 (*Char. Gen.*, 117) under 'Dioicia monandria'. Later, Bentham and Hooker [*Gen. Pl.*, 3 (1880), 134] accommodated the genus in the Chloranthaceae. Nine more species have been added on subsequently, bringing the total number to ten. In connection with a comparative morphological and anatomical study of the Chloranthaceae, the results of which are to be published elsewhere, the author had a unique opportunity of assembling and examining an extensive collection in which the species of *Ascarina* were particularly well represented. The exomorphic and endomorphic characters of this genus are very clearly delimited from the other genera of the family, — *Chloranthus*, *Sarcandra*, and *Hedyosmum*.

HABIT.

The representatives of the genus are densely branching shrubs or small trees with slender trunk, growing mostly at altitudes between 200–1,000 meters, and up to 2,000 meters in the Philippines. Individuals inhabiting rather exposed regions often present a gnarled appearance with close branching. The apices of such branchlets frequently bear excessively crowded leaves, which feature is obviously due to a failure of the concerned internodes to undergo normal elongation. Irrespective of the habitat, the smaller branchlets are almost always terete, longitudinally striate, and characteristically swollen at the nodes, presenting the appearance of a 'jointed stem'.

FOLIAGE.

The leaves are arranged in a typically decussate phyllotaxy in the juvenile as well as in mature twigs. The bases of opposite leaves fuse to form a vaginate sheath, denticular processes of stipular nature arising from its rim on either side of the petiole. The lamina is coriaceous in varying degrees and this character appears to be influenced in a large measure by the habitat. Thus, this character is not dependable in distinguishing the species. In the past, one of the chief points of differences between *A. philippinensis* and *A. reticulata* was said to be the chartaceous and coriaceous nature of the leaves respectively in the two species. However, an examination of a large representative collection of both species would readily convince that the two types of leaves with a series of intergrading forms are borne not only on different specimens of both the species, but also on one and the same specimen in sporadic instances.

The general shape of the leaf appears to be fairly stabilized in several species; however, great caution is required in judging the limits of variability within

a species before making use of this character in identifying different species. In contrast, the size of lamina and the nature and degree of serration are subject to wide fluctuation, and therefore do not form reliable criteria to be employed in distinguishing specific or subspecific units. *A. lanceolata* exemplifies these variables very clearly. As Guillaumin has observed [*Jour. Arnold Arb.*, 13 (1932), 82], the leaves of plants growing at Tanna differ from the typical form of Fiji and Samoa Islands in the larger leaves and the larger petioles, while those from Aneityum has narrower lanceolate leaves. Similarly, considerable fluctuation in the size of lamina is met within plants collected from Rarotonga Island, which happens to be the type locality.

INFLORESCENCE.

There are some species in which the inflorescence is axillary, some others where it is terminal, and a few others with both kinds. This character provides a valuable clue, among others, in segregating the species; so also characters like, the length of the individual spike of inflorescence, the approximate number of flowers or fruits borne by them, and the congested or lax spacing of flowers. Fundamentally, the inflorescence of *Ascarina* may be classified as a compound spike. Generally three main axes arise simultaneously from the axils of leaves in the case of an axillary inflorescence, or one main axis in continuation of the extremity of the twig and two others on either side of it from the axils of the last pair of leaves in the case of a terminal inflorescence, so as to appear to have had a simultaneous origin from a common point. In either case, the median branch almost invariably divides into 2, 3 or 5 branches, the individual branches being more or less of a uniform length and bearing approximately a uniform number of flowers or fruits.

In some species, the individual flower is subtended by a single bract, while in others by three bracts,—a larger median outer one partly enclosing two laterally placed inner ones of decidedly smaller dimensions. This difference in the number of bracts per flower affords a very helpful clue in recognizing two distinct sections within the genus.

In some collections from Fiji and New Hebrides, the female flowers are arranged in pairs on the inflorescence. Each flower (i.e., the pistil) of the pair is surrounded by three bracts, all of similar size and shape, and the pair of flowers with their six bracts are in turn subtended by a large and fleshy bract (see the illustrations of *A. lanceolata* var. *Smithii*). This feature appears very consistently in association with longer petioles and a different norm of the leaf-shape.

FLOWER.

The plants are dioecious. The flowers are devoid of a perianth and in this sense are naked. In the case of the female flower, the base of the pistil is somewhat encircled and enclosed by the subtending bract or bracts. The pistil is solitary, styleless, with a characteristically bilipped and hairy stigma. The dorsal lip (i.e., the one situated away from the inflorescence axis) protrudes beyond the ventral one (i.e., nearer to the inflorescence axis), the latter being crescent-shaped and surrounding the dorsal lip partially. The ovary is unilocular lodging a single anatropous ovule which is suspended from the apex. The male flower of species with a single subtending bract bears two stamens, and of those with three subtending bracts, a single stamen. This set of characters has provided a strong basis for dividing the species under two distinct categories as will be seen later. The stamen is sessile somewhat cylindrical, sometimes curved away from the axis, quadrilocular, with a short cone-shaped sterile apex. The pollen grains are typically monocolpate with sculpturings both on the exine and the external face of the germinal furrow.

Rather occasionally one meets with male inflorescences of some specimens of *A. lanceolata* and of *A. lucida* showing the presence of a rudimentary pistil in the flowers. In such instances the pistil occupies the adaxial and the stamen the abaxial positions. This phenomenon of pseudo-bisexuality appears to be an abnormality.

FRUIT.

The fruit is typically a drupe, very small (maximum size, 3 mm. long \times 2 mm. broad), generally ovoid, with persistent stigmatic crest. The exocarp is succulent, thin, and smooth or wrinkled when dry. The endocarp is stony, somewhat discoid and rather fragile; in species with a single subtending bract the external surface is typically smooth, whereas in species with three subtending bracts the surface is characteristically warty-papillate. The seed contains abundant endosperm and a significantly small embryo.

LOCAL NAMES, USES.

A. lanceolata is known by the following local names: ikurangi, maungaroa, temanga, tekou, kaitaea (Rarotonga); afia, tongo vao, fiti (Samoa). There does not appear to be much economic value for the plants. Powell [*Jour. Bot.*, 6 (1868), 278] writes with reference to *A. lanceolata*: 'Much esteemed by the natives as a perfume, and eagerly sought from Ta'u by the inhabitants of the other islands. The leaves are dried in the sun, and then mixed with the newly-expressed cocoa-nut oil used for anointing their bodies. With the dried leaves pillows are stuffed.'

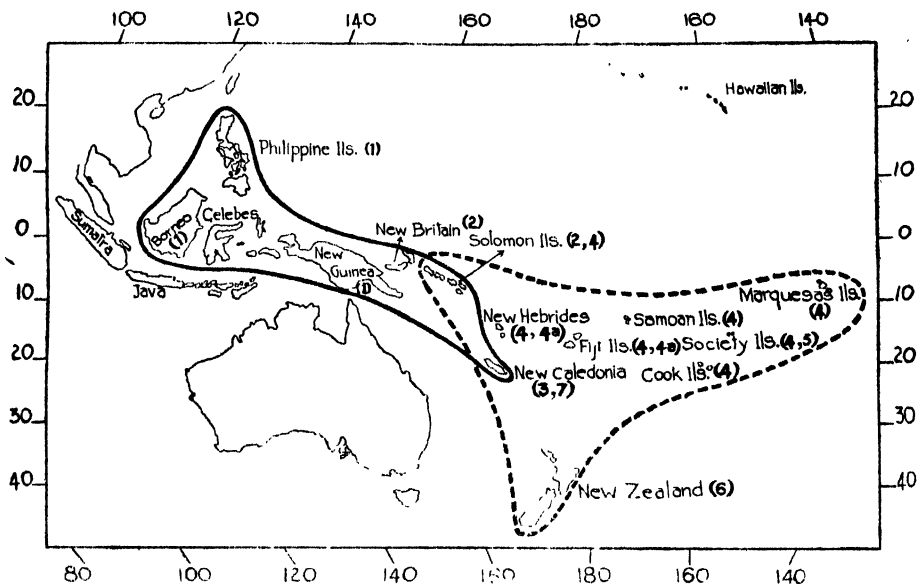
CONCLUSIONS.

The number of subtending bracts per flower, the number of stamens in a flower, and the smooth or warty-papillate feature of the endocarp may be profitably employed for recognizing two main sections under the genus. Combination of characters like the length of individual branches of the inflorescence and the number of flowers borne on them, the axillary or terminal nature of the inflorescence, the general norm of leaf shape, constitute fairly reliable criteria for the segregation of species. Recognition of a species on any one of these characters alone would lead to confusion.

The distinguishing characters of the two categories of species suggested above may be mentioned as follows: GROUP I: subtending bract per flower single, endocarp smooth, and male flower with two stamens; GROUP II: subtending bracts per flower three, endocarp warty-papillate, and male flower with a single stamen.

GEOGRAPHICAL DISTRIBUTION.

When species of *Ascarina* are accommodated under these two categories, the first group consists of *A. philippinensis*, *A. Maheshwarii*, and *A. Solmsiana*, and the second, of *A. lanceolata*, *A. polystachya*, *A. lucida*, and *A. rubricaulis*. The species of the first group have a predominantly 'western' distribution and those of the second a predominantly 'eastern' distribution (Fig. I). A small overlap of western and eastern elements occurs in Solomon Islands (*A. Maheshwarii*, western and *A. lanceolata*, eastern) and in New Caledonia (*A. Solmsiana*, western and *A. rubricaulis*, eastern). Of the species of the western group *A. philippinensis* has a wide distribution, and of the eastern group, *A. lanceolata*, *A. Solmsiana*, *A. polystachya*, and *A. lucida* have been collected only from New Caledonia, Society Islands, and New Zealand respectively, and appear to be endemic species.



TEXT-FIG. 1. Approximate known distribution of the genus *Ascarina*. Numbers in parentheses after localities refer to the corresponding species treated in the text: (1) *A. philippinensis*. (2) *A. Maheshwarii*. (3) *A. Solmsiana*. (4) *A. lanceolata*. (4a) *A. lanceolata* var. *Smilhi*. (5) *A. polystachya*. (6) *A. lucida*. (7) *A. rubricaulis*. The heavy continuous line indicates the limits of the 'western' group, and the broken line, that of the 'eastern' group.

MATERIALS.

Herbarium specimens belonging to the following institutions have been examined, and the respective abbreviations used in annotation are mentioned against the names:

Arnold Arboretum, U.S.A. . . . .	..	..	..	..	A
Bishop Museum, Honolulu, Hawaii . . . . .	..	..	..	..	BISH
British Museum (Natural History), London . . . . .	..	..	..	..	BM
Gray Herbarium, U.S.A. . . . .	..	..	..	..	G
Herbarium Bogoriense, Bogor, Java . . . . .	..	..	..	..	B
New York Botanical Garden, U.S.A. . . . .	..	..	..	..	NY
Royal Botanic Gardens, Kew . . . . .	..	..	..	..	K
United States National Herbarium, Washington D.C. . . . .	..	..	..	..	US
University of California, Berkeley . . . . .	..	..	..	..	UC

ACKNOWLEDGEMENTS.

I am deeply obliged to the above institutions for placing at my disposal their respective collections. I am grateful to the National Institute of Sciences of India, Prof. T. S. Sadasivan, and the Madras University for giving me opportunities to complete this investigation, among others. I am thankful to Prof. H. Santapau for the Latin description of *A. Maheshwarii* and of *A. lanceolata* var. *smithii*.

ARTIFICIAL KEY TO THE SPECIES.

Group I—Subtending bract of flower single, male flower with two stamens, endocarp smooth.

Inflorance terminal, axis thick, spacing of fruits congested, exocarp wrinkled (when dry), drupe 1.5×2.0 mm. to 2.5×3.0 mm., averaging 2.0×3.0 mm. . . 1. *A. philippinensis*.

Inflorescence terminal and axillary, axis slender, spacing of fruits lax, exocarp smooth (when dry), drupe 1.2×1.8 mm. to 1.5×2.5 mm.

Leaves obovate, typically obtuse, cuspidate, finely serrate
.. 2. *A. Maheshwarii*.

Leaves typically lanceolate, acuminate, coarsely serrate
.. 3. *A. Solmsiana*.

Group II—Subtending bracts of flower three, male flower with one stamen, endocarp warty-papillate.

Individual spikes of inflorescence 5–10 cm. long in post-fertilization stages, flowers per spike 50–100

Female flowers on the spike single

Leaves lanceolate, acuminate, serrate

.. 4. *A. lanceolata*.

Leaves elliptic-ovate, obtuse, crenate-serrate

.. 5. *A. polystachya*.

Female flowers on the spike in pairs, each pair being subtended by a somewhat fleshy bract; leaves elliptic oblong, acute, crenate-serrate .. 4a. *A. lanceolata* var. *Smithii*.

Individual spikes of inflorescence 1.5–3.0 cm. long in post-fertilization stages, flowers per spike 20–30.

Inflorescence essentially terminal; leaves elliptic-oblong, obtuse to bluntly acute, obtuse-serrate

.. 6. *A. lucida*.

Inflorescence essentially axillary, leaves lanceolate, acuminate, serrate .. 7. *A. rubricaulis*.

DESCRIPTION OF THE GENUS AND SPECIES.

Ascarina Forst.

Char. Gen. (1776), 117, t. 59.

Aromatic glabrous shrubs or small trees; dioecious; branches slender, young twigs terete, swollen at the nodes; leaves decussate, petiolate, petiolar bases connate forming a sheath; stipules minute emerging from the margin of the vaginate sheath on either side of petiole; lamina lanceolate or ovate-lanceolate or elliptic, base cuneate, apex acute or acuminate or obtuse, margin glandular-serrate excepting at the base; inflorescence terminal and subterminal or axillary or both, generally a pendulous compound spike; main branches generally 3, the median one often bi- or tri-fid; bract subtending the flower minute, 0.5–0.75 mm. long, persistent, single or 3, median 0.5–0.75 mm. long and the two laterals still smaller; perianth absent; male flower: stamen single or 2, anther sessile, cylindrical, usually slightly curved away from the inflorescence axis, apex acuminate or blunt, thecae 4, in two pairs, parallel, dehiscence latrorse and longitudinal; pollen grains monocolpate, spore wall minutely reticulate; female flower: pistil solitary, ovoid to globose, style absent, stigma sessile, unequally bilipped, tufted, abaxial lip protuberent, surrounded at the base by the crescent-shaped non-protuberent adaxial lip; locule 1, ovule 1, orthotropous, suspended from the apex of locule; fruit a drupe, dried up stigmatic crest conspicuous; exocarp succulent, thin; endocarp stony, fragile, externally smooth or warty-papillate; endosperm abundant; embryo minute.

1. *Ascarina philippinensis* C. B. Rob. in *Philippine Jour. Sci.*, 4 (1909), 70.

Ascarina reticulata Merr. in *Philippine Jour. Sci.*, 12 (1917), 263.

Tree, 6–8 m: tall, young branchlets smooth; leaves papyraceous to thickly coriaceous and somewhat shiny, 3.2×1.8 , 3.7×2.3 , 4.5×2.5 , 5.5×2.8 , 6.0×3.0 cm.

long and broad, petiole 0.5-1.0 cm. long, lamina elliptic or oblong, margin evenly crenate-serrate excepting towards the base, apex obtusely acuminate or acute, base broadly cuneate; inflorescence terminal, axis and branches rather thick and short, individual branch 1.0-1.5 cm. long, flowers densely crowded all along the axes; subtending bract 1, ovate, subacute, 2.0-2.5 mm. long, persistent; male flower: stamens 2, placed side by side, about 3.0 mm. long and 1.0-1.5 mm. broad, anther sessile, connective prolonged into a short subacuminate apex; female flower: pistil 1, ovoid, stigma strongly and unequally bilipped; fruit ovoid, generally black, wrinkled when dry; endocarp smooth, discoid, flattened into a wing-like fringe along the margin of the disc.

SPECIMENS EXAMINED.

PHILIPPINES: without specific locality, *Williams 2537* (A). Luzon: Ilocos Notre Province, Mt. Palimlim, *Ramos, Bur. Sci. 33323*, Aug. 1918 (A, K, US); Nueva Ecija Province, Mt. Umingan, alt. 400 m., *Ramos & Edano, Bur. Sci. 26399*, August 19, 1916 (A, K, US *COTYPES* of *Ascarina reticulata* Merr.); Rizal Province, Montalban, *Loher 12840*, March 1909 (UC), Oriud, *Loher 13835*, March 1914 (A, UC); Isabela Province, Mt. Moises, *Clemens 16887*, April 1926 (BM, NY, UC); Tayabas Province, Mt. Alzapan, *Ramos & Edano, Bur. Sci. 45694*, May-June, 1925 (A, BM, NY, UC). Panay: Antique Province, no specific locality, *McGregor, Bur. Sci. 32332*, May-August, 1918 (NY); Capiz Province, Mt. Madias, *Ramos & Edano, Bur. Sci. 30647*, April-May, 1918 (A, B, BM, K). Mindanao: Todaya, Mt. Apo, alt. 2,166 m., *Williams 2541*, March 31, 1905 (K, NY *COTYPES*); alt. 2,000 m., *Elmer 11480*, August 1909 (A, B, BISH, BM, G, K, NY, US); Bukindon Subprovince Mt. Lipa, *Ramos & Edano, Bur. Sci. 38559*, June-July, 1920 (A, B, BM, G, K).

BORNEO: British North Borneo: Mount Kinabalu, Marai Parai, alt. 1,500 m., *Clemens 32391*, March 27, 1933 (A, B, K), alt. 2,333-2,666 m., *Clemens*, no number, April 25, 1933 (B); Kinataki River, alt. 2,666 m., *Clemens 31932-32919* February 25-27, 1933 (A, B, K, UC); Central East Borneo: W. Koetai, alt. 600 m., *Ender 4493*, October 22, 1925 (B).

NEW GUINEA: Dutch New Guinea: 9 km. N.E. of Lake Habbema, alt. 2,800 m., in primary forest alt. 2,470, *Brass & Versteegh 10475*, October 21, 1938 (A); 15 km. S.W. of Bernhard Camp, Idenburg River, in rain-forest on slopes, alt. 1,194 m., *Brass & Versteegh 11944*, January 18, 1939 (A). North-eastern New Guinea: Morobe District, Ogeramnang, alt. 2,000 m., *Clemens 4807*, December 31, 1936 (A), alt. 1,933 m., *Clemens 5123*, January 25, 1937 (A). North-western New Guinea: Wissel Lake Region, Enarotali-Koegapa heath country, *Eyma 4823*, March 29, 1939 (B).

Notes.—(i) This species is related to *A. Maheshwarii*, but differs from it in exhibiting distinctly smaller-sized leaves, only terminal inflorescences, densely crowded arrangement of female flowers and fruits of black colour.

(ii) The present is the first account to describe the male plants of this species. The similarity of the vegetative characters between the male and female plants is rather remarkable.

(iii) An examination of a large number of collections of *A. reticulata* Merr. indicates that there are no valid reasons to retain it as a distinct species from, or even as a variety of *A. philippinensis*. That the supposed difference in leaf texture in the two species is not a dependable character has already been alluded to in an earlier part of this paper. The number of lateral nerves per leaf also does not constitute a significant difference in the two species. As to the black colour of dried specimens of *A. reticulata* in contrast to the brownish-white of *A. philippinensis* it must be observed that these differences appear to be responses to methods of collection and of drying. Thus the characters clearly and wholly overlap in the two species, and hence *A. reticulata* is merged with *A. philippinensis*.

2. *Ascarina Maheshwarii* Swamy, spec. nov.

Accedit ad *A. philippinensem* multis in partibus, ab ea tamen differt sequentibus notis: folia maiora sunt atque formae diversae, inflorescentia est et terminalis et axillaris, flores vero sunt laxe spicati, et fructus maturus est fusce brunneus.

Arbor tenuis, 10–12 m. alta. *Folia* coriacea, 8.5×4.3 , 11.3×5.7 , 12.0×5.0 , 14.2×8.0 cm.; petiolus 1.0–2.0 cm. longus, 0.2–0.3 crassus; lamina ovata vel obovata marginibus serratis vel crenato-serratis, apice cuspidato, basi cuneata. *Inflorescentia* terminalis aequae ac axillaris, spica composita constans 5–8 ramis, qui sunt tenues, atque 2.5–3.0 cm. longi, floribus inter se sat bene spatatis; bractea floralis unica, late lanceolata, 1.0–1.5 mm. longa. *Flos masculus*: stamina duo, quorum singula ad latus alterius sunt apposita, sessilia, 2.0–3.0 mm. longa, ca. 1.0 mm. lata. *Flos femineus*: pistillodium 1, ovoideum, stigmate sessili inaequaliter bilabiato. *Fructus* ovoideus et ut plurimum fusce brunneus in sicco; exocarpium tenue, succulentum, laeve in sicco; endocarpium laeve, plus minusve discoideum.

SPECIMENS EXAMINED.

SOLOMON ISLANDS: Bougainville Island: Kupei Gold Field, in rain, forest, alt. 950m., *Kajewski 1681*, April 10, 1930 (A TYPE of female plant, BISH-BM); Koniguru, Buin, in rain-forest, alt. 800 m., *Kajewski 2011*, August 2, 1930 (A TYPE of male plant, BISH, BM, US), common name *Tubilai*. San Cristoval Island: Hinuahaoro, in mountain forests, alt. 900 m., *Brass 3020*, April 22, 1932 (A, BISH).

NEW BRITAIN: New Pomeru: Kuropo, Maisua, alt. 600 m., *Waterhouse y82*, September 1932 (K, NY).

This species is named after Prof. P. Maheshwari, University of Delhi, Delhi.

3. *Ascarina Solmsiana* Schlechter in *Engl. Jahrb.*, 39 (1906), 94.

Shrub or small tree, densely branching; leaves chartaceous, 6.0×1.0 , 7.0×1.7 , 8.5×2.2 , 9.0×2.5 cm. long and broad, petiole 0.8–1.0 cm. long; lamina lanceolate, margin coarsely crenate-serrate, apex acuminate, base cuneate; inflorescence terminal, five-branched, arrangement of flowers on spike rather lax, individual branch 3.0–3.5 cm. long; male flower not known; female flower: subtending bract 1, lanceolate, about 2.0 mm. long, pistil 1, sessile, subovoid; fruit ovoid, exocarp smooth, thin; endocarp smooth, slightly discoid, faintly winged along the margin of the disc.

SPECIMEN EXAMINED.

NEW CALEDONIA: Cu-Hinna: *Schlechter 15619*, January 7, 1903 (BM, K. COTYPES).

Notes.—This species differs from *A. philippinensis* and *A. Maheshwarii* by the possession of linear lanceolate, coarsely serrate leaves and terminal inflorescences.

4. *Ascarina lanceolata* Hook. f. in *Jour. Linn. Soc.*, 1 (1856), 129.

Ascarina subfalcata J. W. Moore in *Bull. Bishop Mus.*, Honolulu, No. 102 (1933), 26.

Bushy shrub or small tree, 5–12 m. tall; leaves 5.0×1.5 , 7.0×2.0 , 8.0×2.5 , 10.0×2.8 , 14.5×4.5 cm. long and broad, coriaceous, petiole 0.5–2.5 cm. long, lamina lanceolate, or less frequently ovate-lanceolate, margin minutely or grossly serrate, base cuneate, apex acuminate; inflorescence terminal as well as in the axils of one or two penultimate pairs of leaves; median axis of inflorescence trifurcate, the central branch bifid; penultimate inflorescences solitary and unbranched; individual branch 5.0–10.0 cm. long in post-fertilization stages; flowers single; subtending bracts 3 per flower, a larger median and two smaller laterals; median bract variable in shape, lanceolate-acuminate to ovate-obtuse; lateral bracts broad-

lanceolate or denticulate; male flower: stamen 1, 0.3-0.4 mm. long, about 0.1 mm. broad, deltoid sterile apex protruding beyond the thecae; female flower: pistil ovoid, about 1.5 mm. long, slightly less in breadth; fruit 2.0-3.0 mm. long, 2.0-2.5 mm. broad, exocarp slightly wrinkled when dry, thin; external surface of endocarp warty-papillate.

SPECIMENS EXAMINED.

SOLOMON ISLANDS: Bougainville Island: Koniguru, Lake Luralu, in rainforest, alt. 900 m., *Kajewski* 2173, August 29, 1930 (A, BISH).

NEW HEBRIDES: Aneityum Island: Anelgauhat Bay, alt. 400 m., *Kajewski* 863, March 5, 1929 (A, BISH, K, NY, US); Ambrym: Mt. Eoio, alt. 900 m., La Rüe, no number, September 15, 1936, ex herb. Mus. Paris (A).

FIJI ISLANDS: With no specific locality, collected during U.S. Exploring Expedition under Capt. Wilkes, 1838-42, bearing U.S. Nat. Herb. No. 40438 (G. US).

SAMOA: With no specific locality, *Powell* 237 (K), *Whitnee* 93 (G, K); Savaii: Maugaloa, alt. 1,200 m., *Vaupel* 494, September 22, 1906 (BISH, K, NY, US); Tuisios range, alt. 1,600 m., *Christophersen* 820, September 24, 1929 (BISH, K, NY), *Christophersen* 2167 (K); above Matavanu, alt. 1,000 m., *Christophersen & Hume* 2014, July 15, 1931 (BISH, US), alt. 900 m., *Christophersen & Hume* 1996, July 14, 1931 (BISH, US), alt. 1,300 m., *Christophersen & Hume* 2153, July 24, 1931 (BISH), *Christophersen & Hume* 2167, July 25, 1931 (NY). Upolu: Fao, at top, alt. 680 m., *Christophersen* 571, September 6, 1929 (A, BISH).

COOK ISLANDS: Rarotonga, summit of Manngotia, alt. 366 m., *Parks* 22521 (TOPOTYPE), June, 1929 (BISH, G, K, NY, UC, US), *Parks* 22248, June 9, 1929 (K, UC, US); Ikurangi, alt. 66-600 m., *Wilder* 827, April 16, 1929 (BISH); summit of highest peaks, alt. 500-999 m., *Cheeseman* 645, June 1899 (K).

SOCIETY ISLANDS: Island of Raiatea: Ridge South end of Opoa Mountain, West facing slope, alt. 200 m., *Moore* 657, March 5, 1927 (BISH TYPE of *Ascarina subfalcata* J. W. Moore).

MARQUESAS ISLANDS: Nikuhiva: Hakui upper plains, alt. 1,033-1,100 m., *Quayle* 1319, October 10, 1922 (BISH).

Notes.—(i) This species exhibits considerable degree of polymorphism in regard to the extent of elongation of internodes, the length of petiole, leaf size and less frequently the shape, the nature and degree of serration of leaf margin, and texture. At least some of these characters appear to be correlated with the altitudinal variation. However, an examination of more representative collections is necessary to determine if there are ecological or geographical races within the species either in respect to altitude or with reference to factors of isolation of the islands on which the species thrives. Therefore it appears inadvisable at present to recognize subspecific units.

(ii) In some collections (e.g. *US* 40438) the male inflorescence bears 'pseudo-bisexual flowers'. In such examples, the incipiently developed pistil is placed next to the inflorescence axis, and the stamen arises separately towards the abaxial side. This phenomenon appears to be just an abnormality.

4a. *Ascarina lanceolata* var. *Smithii* var. nov.

Varietas haec clare distincta apparet ob notas sequentes: folia sunt elliptico-oblonga; bractea carnosa, ampla adest praeter tres alias bracteas aequales cuiusque floris, quae duos flores femineos subtenit.

Arbor tenuis, 5-10 m. alta. Folia 5.0×2.3, 7.0×3.3, 8.0×3.5 cm.; coriacea, petiolo 1.5-2.5 cm. longo, lamina elliptico-oblonga, acuta ad apicem, marginibus crenatis, basi cuneata. Inflorescentia ut plurimum tantum terminalis, trifurca, ramo medio bifido; inflorescentia ex axillis foliorum penultimorum, si adest, non ramosa; rami singuli 4.5-6.0 cm. longi ad anthesim. Flores masculus: unicus, suffultus tribus bracteis, media quidem largiore, lateralibus minoribus; stamen unum,

ca. 0.3 cm. longum, 0.1 cm. latum. *Flores feminei*: bini, singuli circumdati tribus bracteis ut in masculo flore, hac vero bracteae sunt similes inter se magnitudine et forma; singula paria florum in vicem suffulta una bractea lata, aliquantum carnosae; pistillodium ca. 0.1 mm. longum. Fructus ignotus.

SPECIMENS EXAMINED.

FIJI: With no specific locality, *Seemann 564* (G, K); Taveuni, summit of Ului-galau, alt. 1,100–1,220 m., in dense thickets, *Smith 908*, January 3, 1934 (BISH, G TYPE, K, NY, UC, US).

NEW HEBRIDES: Tanna Island: Mt. Tokosh Meru, in rain-forest, alt. 1,000 m., *Kajewski 152*, March 15, 1928 (A, K, NY).

5. *Ascarina polystachya* Forst. *Char. Gen.* (1776), 117.

Ascarina raiteensis J. W. Moore in *Occ. Papers, Bishop Mus.*, Honolulu, 10 (1934), 7.

Shrub, 1–2 m. tall; leaves 5.8×2.5 , 7.0×3.0 , 8.5×3.8 , 10.0×4.5 cm. long and broad, somewhat coriaceous, petiole 1.0 cm. long, lamina elliptic-ovate, apex obtuse, occasionally emarginate, margin crenate-serrate excepting in the basal quarter, base cuneate; veins rather embossed on the ventral surface; inflorescence terminal, a compound spike, 3-forked, the median fork again branching into two or three, individual branch 7.0–9.0 cm. long at anthesis; flowers single, subtending bracts 3, median one larger and somewhat enclosing the smaller triangular laterals; male flower: stamen single, 0.5–0.6 cm. long, 0.15–0.2 cm. broad, anther sessile, prominently curved away from the axis; female flower: ovary 2.0 mm. long, 1.5 mm. broad; fruit 2.5 mm. long, 1.75–2.0 mm. broad with bilipped persistent stigma; exocarp almost smooth, endocarp warty-papillate.

SPECIMENS EXAMINED.

SOCIETY ISLANDS: Tahiti: with no specific locality, collected during the U.S. South Pacific Exploring Expedition under the command of Capt. Wilkes, 1838–42 (G, K, US); *Moseley* (Challenger Expedition), no number, alt. 1,000 m., (BM, K); ex *US 40534*; Orofena, South ridge, in low upper woods, alt. 1,570 m., *St. John & Fosberg 16981*, September 21, 1934 (BISH); east side of South ridge, in wet wooded ridge, alt. 1,250 m., *St. John & Fosberg 17045*, September 20, 1934 (BISH); south side, moist ridge, alt. 1,500 m., *MacDaniels 1344*, May 16, 1927 (BISH). Raiatea: Temchani Plain, in moist soil, alt. 400 m., *Moore 178*, October 7, 1926 (TYPE of *Ascarina raiteensis* J. W. Moore, BISH).

Notes.—This species is more closely related to *A. lucida*, but differs from it in possessing nearly twice longer individual branches of the inflorescence and doubly larger leaves whose margins are crenate-serrate.

6. *Ascarina lucida* Hook. f. *Fl. Nov. Zel.*, 1 (1855), 228.

Closely branched shrub or small tree, 3–9 m. tall, trunk 15.5–30.0 cm. in diameter; branches slender; leaves 2.5×1.8 , 4.0×1.8 , 5.7×3.1 , 7.3×3.5 cm. long and broad, petiole 0.4–1.0 cm. long, lamina elliptic-ovate, margin coarsely and obtusely crenate-serrate excepting at the base, apex acute, base slightly cuneate; inflorescence essentially terminal, a compound spike consisting of 6–8 individual branches, each branch 3.0–4.0 cm. long; subtending bracts 3 per flower, the median one being the largest and enclosing the smaller laterals; male flower: stamen 1, anther sessile, 0.3–0.35 cm. long, 0.5–1.0 mm. broad, cylindrical, almost straight, apical extremity ending in a small stumpy cone-shaped process; female flower: arranged in clusters or in pseudowhorks on the axis; pistil ovoid to spherical; fruit 1.3–1.5 mm. long, 1.0–1.2 mm. broad, endocarp warty-papillate.

SPECIMENS EXAMINED.

NEW ZEALAND: North Island: Waitii, no definite locality, *Petrie* 1147, November, 1897 (NY); Thames basin. *Petrie* no number, early June, 1907 (UC); South Island: Preservation inlet, no collector's name or number, ex herb. Kirk (A, BM); Cape Foulwind, *Kirk*, no number or date (G); Auckland, *Townson*, no number or date (K); *Banks & Solander*, no number, collected during Cook's first Voyage, 1769-70 (BM, US). Sunday Island: *Cheeseman* 59, August, 1887, mountain tops of the hills (K); *Oliver*, no number, October 7, 1908, West forest (K). Raoul Island: with no specific locality, *Gillivray* 982, July, 1854 (K).

Notes.—(i) This species differs from others by its almost exclusively terminally borne inflorescences, the individual branches measuring 3-4 cm. long, and smaller leaves with coarsely and obtusely serrate margin.

(ii) Sporadically some collections bear hermaphroditic flowers; however, such flowers are as a rule essentially male, since the development of the pistil remains rather incipient. The relative positions of pistil and stamen in these flowers are similar to those described for the abnormal flowers of *A. lanceolata*.

7. *Ascarina rubricaulis* Solms in *DC. Prod.*, 16 (1869), 478.

Small slender tree, 5 m. tall with a heavily branched crown; leaves 5.5×1.0 , 7.5×2.0 , 11.5×3.0 cm. long and broad, petiole 0.5-1.0 cm. long, lamina lanceolate, apex acuminate, margin coarsely serrate, excepting at the cuneate base; inflorescence a compound spike essentially axillary, consisting of 4 or occasionally 5 branches; individual branch short, 1.0-1.5 cm. long, densely crowded with flowers; subtending bract per flower 3, the larger median outer one partially enclosing two smaller laterals; male flower: not seen; female flower: arranged singly on the axis, pistil ovoid with very much pronounced tufted bilipped stigma; fruit ovoid, exocarp almost smooth, endocarp warty-papillate.

SPECIMENS EXAMINED.

NEW CALEDONIA: Balade, Wagap, in mountain forests, *Vieillard* 1212 (BM, G, K *COTYPES*); Paita, 400 m., *Schlechter* 14865, October 1, 1902 (BM, G, K); Mont Mou, *White* 2000, October, 1923 (A, K); with no specific locality, *I. Franc*, UC herb. numbers 390181, 390687; *Pancher*, no number, no date, with no specific locality (BM, K); Mont Canala, alt. 500 m., *Compton* 1193, June 13, 1914 (BM); Nekando, Serpentine scrub, alt. 1,000 m., *Compton* 1085, May 28, 1914 (BM); Mountains to N.W., Serpentine Scrub, alt. 1,000 m., *Compton* 997, May 23, 1914 (BM); Igrambi, alt. 333-1,199 m., *Compton* 1668, August 6, 1914 (BM); Mont Koghi, alt. 999 m., *Compton* 787, April 21, 1914 (BM).

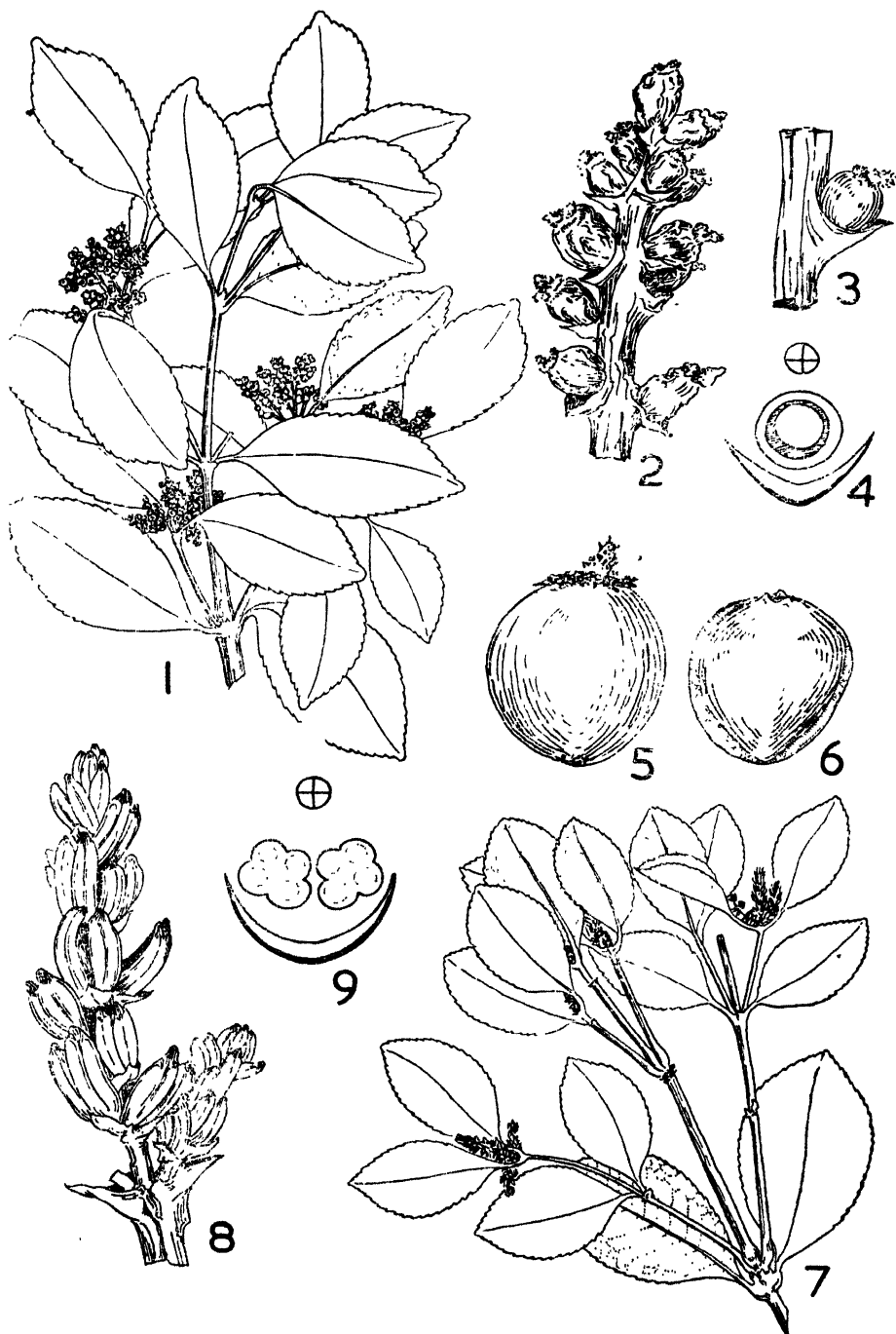
Notes.—This species is distinctive in possessing axillary compound short-spiked inflorescences and typically lanceolate leaves.

EXCLUDED SPECIES.

Ascarina alticola Schlechter in *Engl. Jahrb.*, 39 (1906), 93 = *Paracryphia alticola* (Schltr.) Steen. in *Bull. Bot. Gard. Buitenzorg*, 18 (1950), 459; also see Swamy, B. G. L., *Proc. Nat. Inst. Sci., India*.

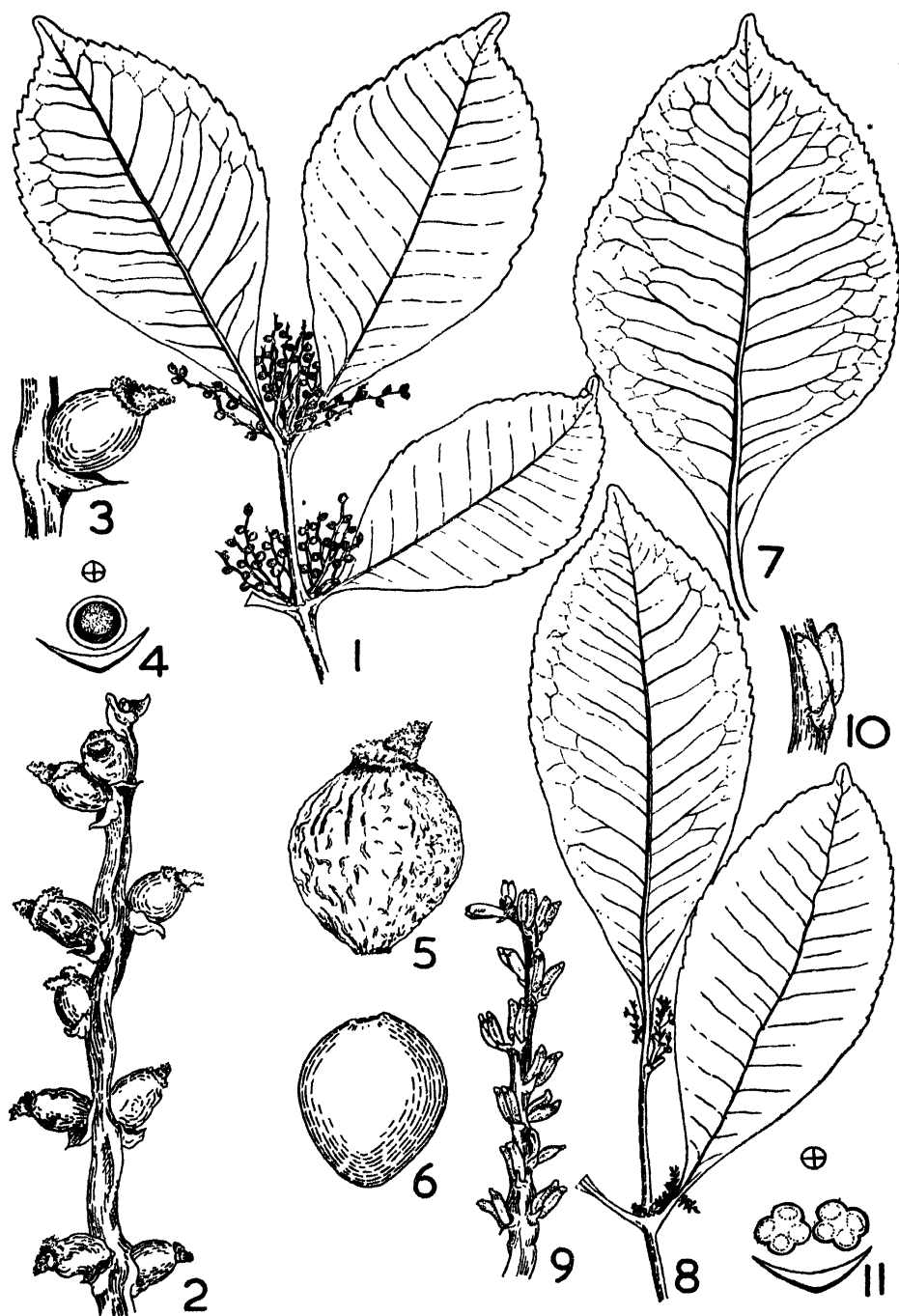
ABSTRACT.

In this monographic study, seven species and one variety of *Ascarina* are recognized. *A. reticulata* Merr., *A. subfalcata* J. W. Moore, and *A. raiteensis* J. W. Moore are reduced to synonymy under *A. philippinensis* C. B. Rob., *A. lanceolata* Hook. f., and *A. polystachya* Forst. respectively. A new species, *A. Maheshwarii* and a new variety, *A. lanceolata* var. *Smithii* have been proposed.



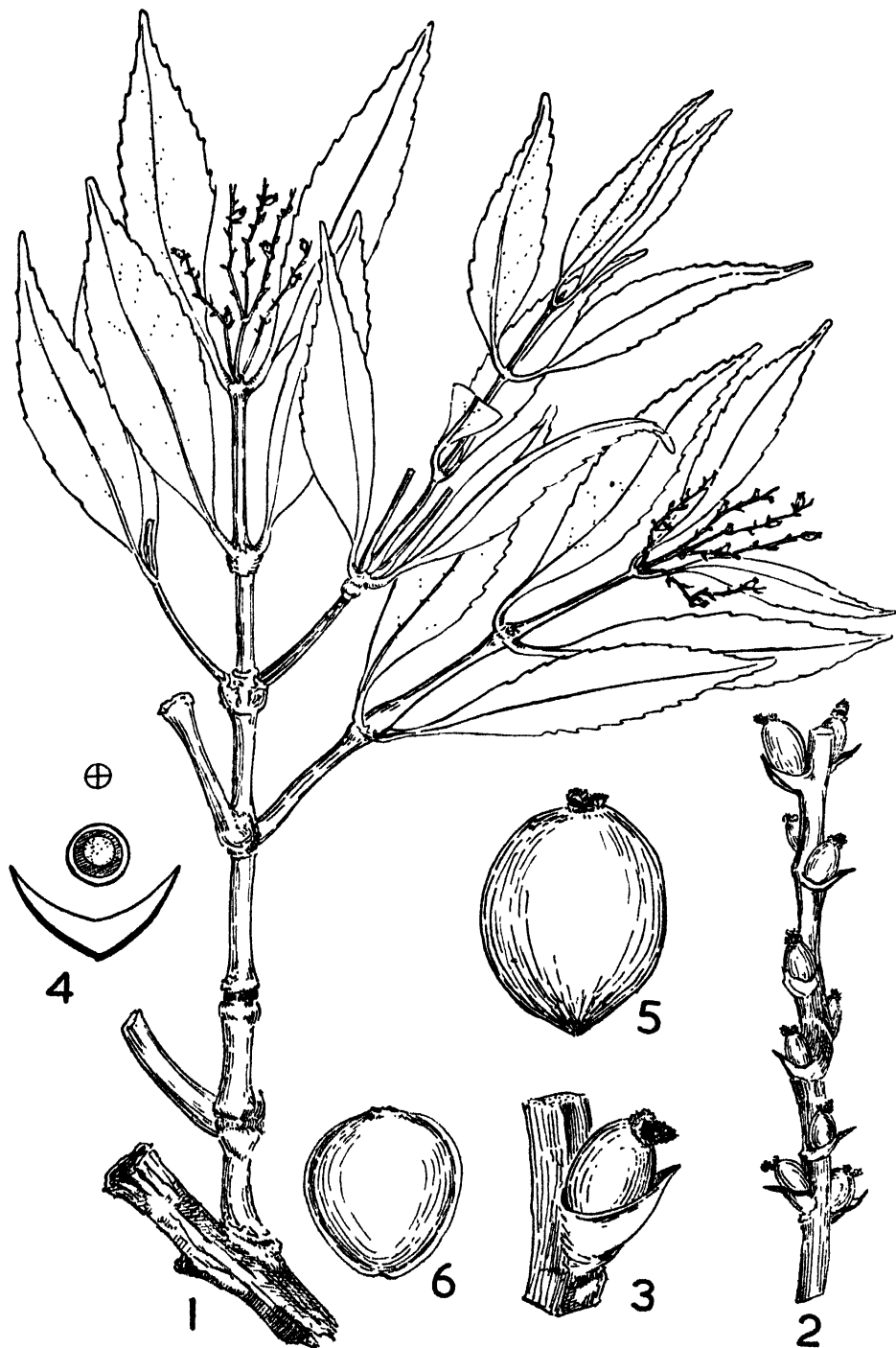
TEXT-FIG. II. *Ascarina philippinensis* C. B. Rob.

1. Female plant (*Bur. Sci.* 38559, A). 2. A part of female inflorescence (*McGregor* 32332, NY). 3. Female flower (*McGregor* 32332, NY). 4. Floral diagram of female flower. 5. Fruit (*McGregor* 32332, NY). 6. Endocarp. 7. Male plant (*Eyma* 4823, B). 8. A part of male inflorescence (*Eyma* 4823, B). 9. Floral diagram of male flower.



TEXT-FIG. III. *Ascarina Maheshwarii*, spec. nov.

1. Female plant (Kajewski 1681, A). 2. A part of female inflorescence (Kajewski 1681, A). 3. Female flower (Kajewski 1681, A). 4. Floral diagram of female flower. 5. Fruit (Waterhouse y82, NY). 6. Endocarp (Waterhouse y82, NY). 7. Isolated leaf (Waterhouse y82, NY). 8. Male plant (Kajewski 2014, A). 9. A part of male inflorescence (Kajewski 2014, A). 10. Male flower (Kajewski 2014, A).



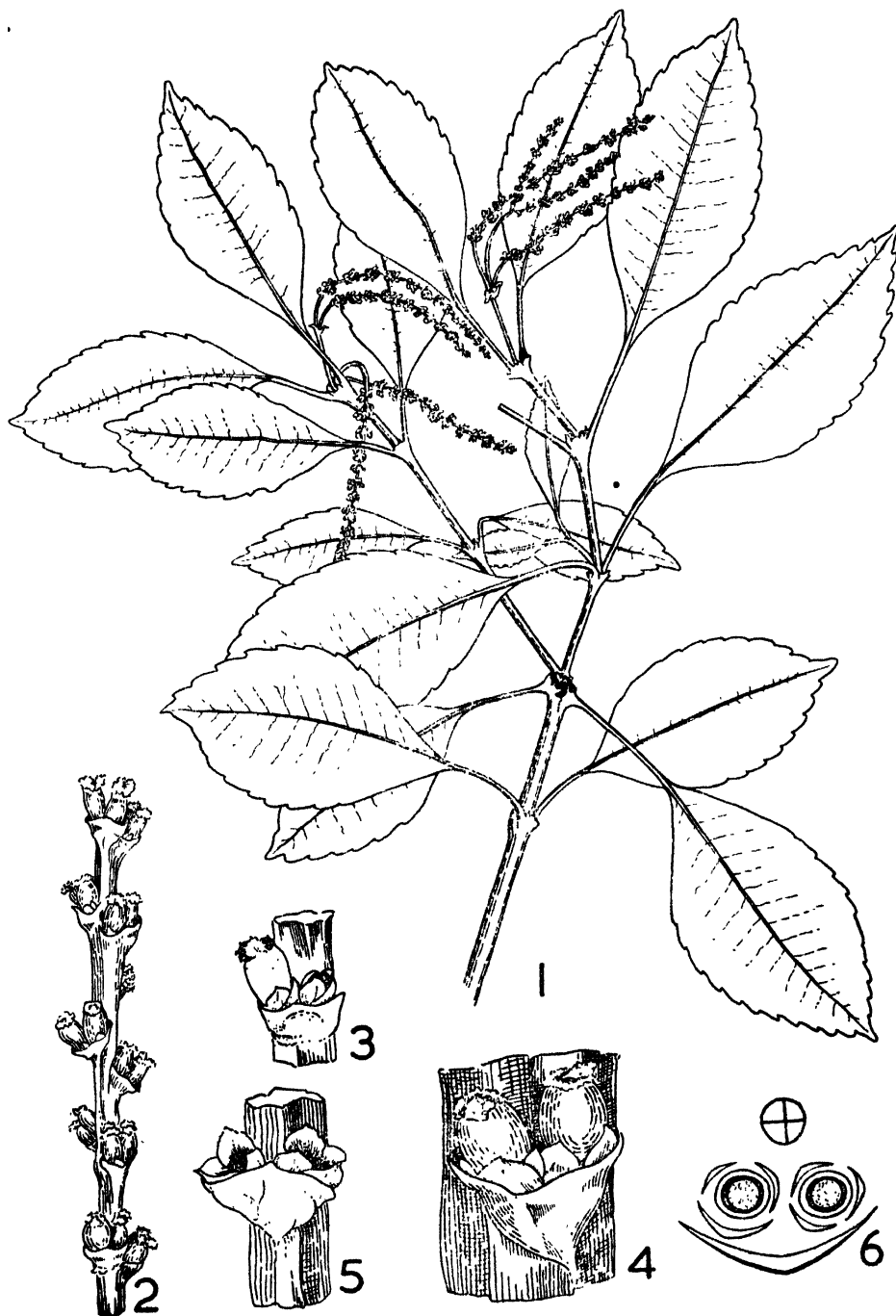
TEXT-FIG. IV. *Ascarina Solmsiana* Schlechter.

1. Female plant. 2. A part of female inflorescence. 3. Female flower. 4. Floral diagram of female flower. 5. Fruit. 6. Endocarp. (All figures drawn from Schlechter 15679, BM.)



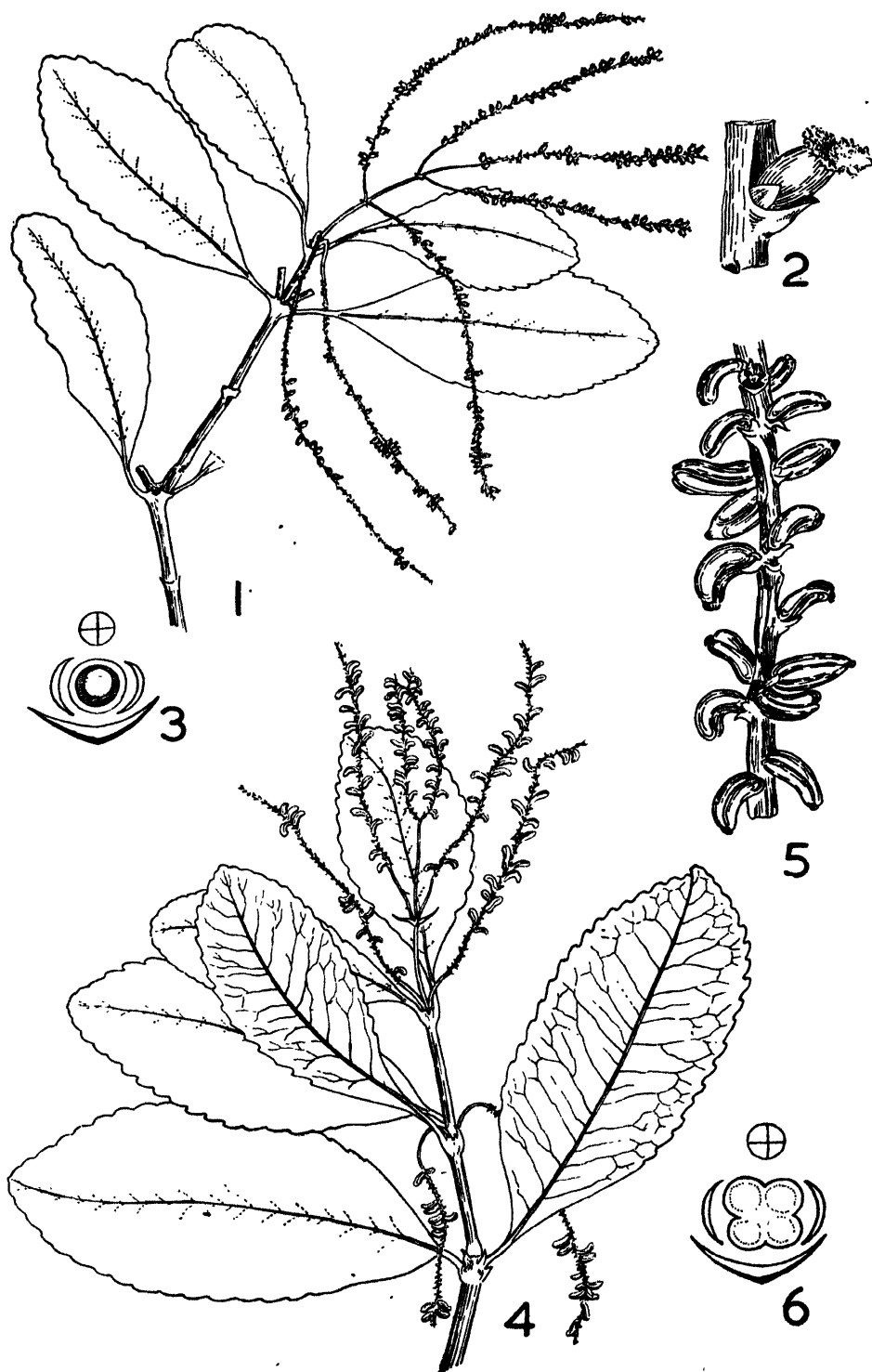
TEXT-FIG. V. *Ascarina lanceolata* Hook. f.

1. Female plant (Parks 22248, US). 2. A part of female inflorescence (Christophersen & Hume 2014, BISH). 3. Fruit (Christophersen 571, A). 4. Endocarp (Christophersen 571, A). 5. Floral diagram of female flower. 6. Male plant (Kajewski 863, NY). 7. A part of male inflorescence (Kajewski 863, NY). 8. Floral diagram of male flower. 9. A pseudo-bisexual flower (US No. 40438.)



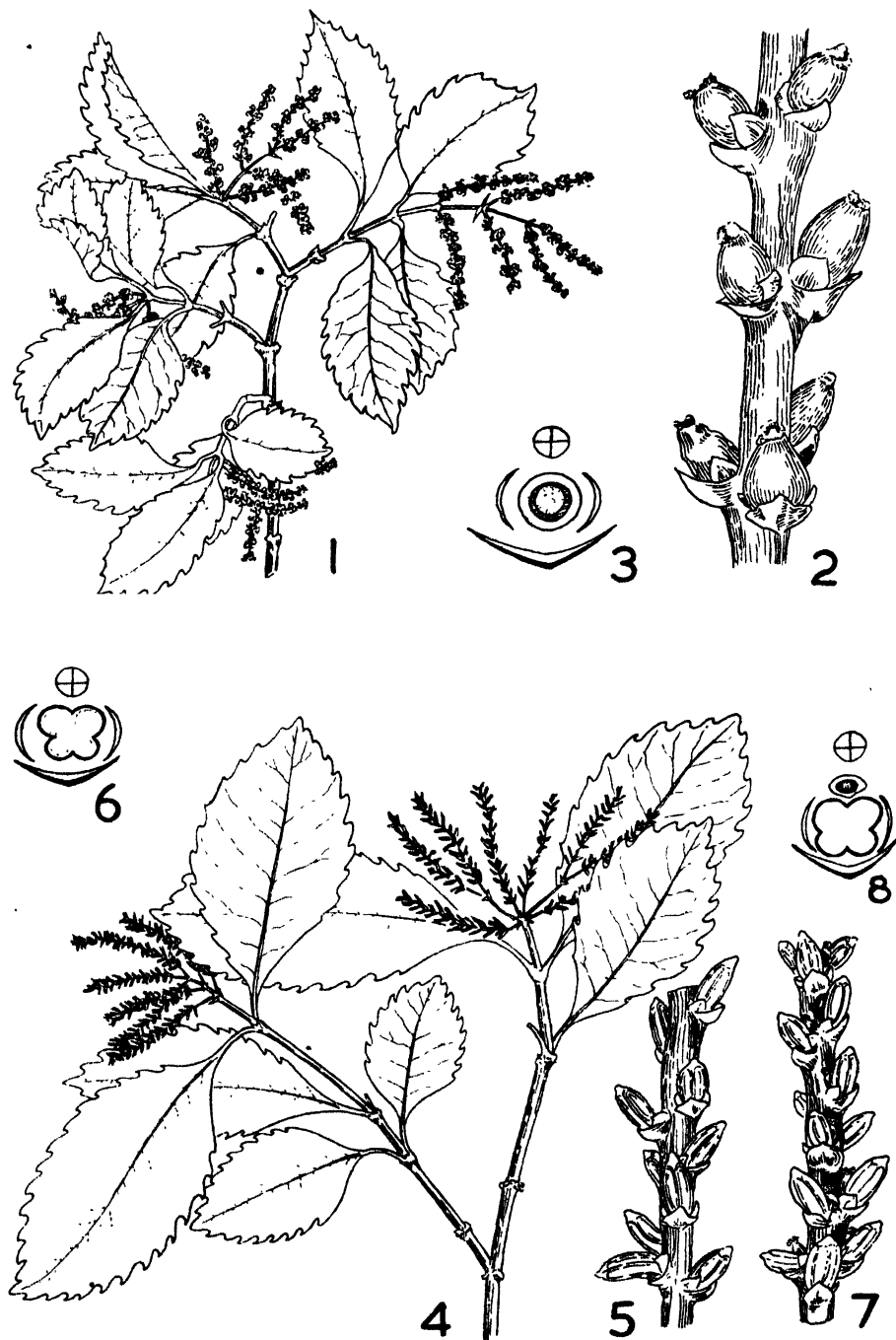
TEXT-FIG. VI. *Ascarina lanceolata* var. *Smithii* var. nov.

1. Female plant. 2. A part of female inflorescence. 3, 4. Female flowers. 5. Female flower, pistil removed to show the arrangement of the system of bracts. 6. Floral diagram of a pair of female flowers. (All figures drawn from *Smith 908*, G, NY, US.)



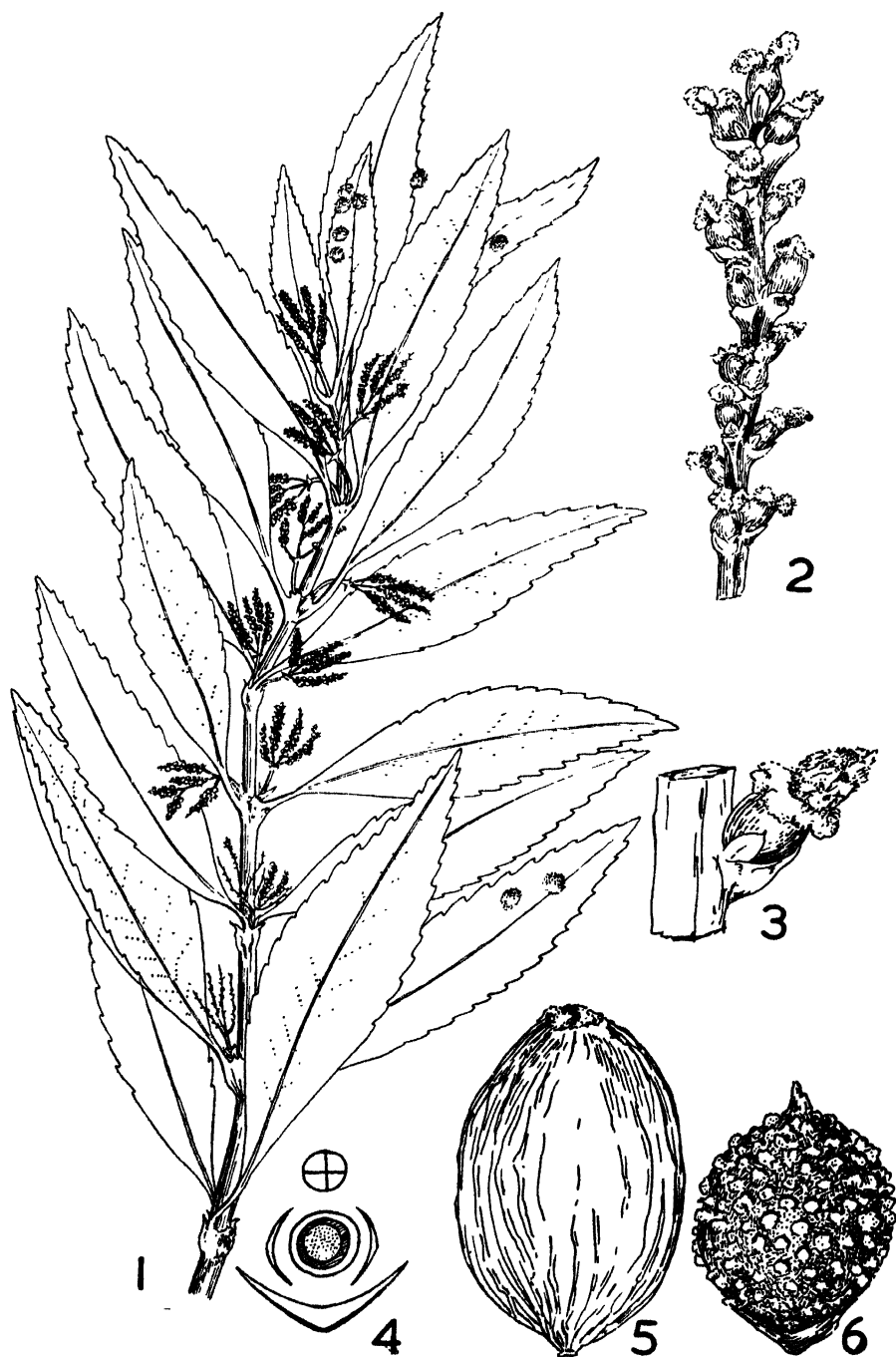
TEXT-FIG. VII. *Ascarina polystachya* Forst.

1. Female plant. 2. Female flower. 3. Floral diagram of female flower. 4. Male plant. 5. A part of male inflorescence. 6. Floral diagram of male flower. (All figures drawn from US No. 40534.)



TEXT-FIG. VIII. *Ascarina lucida* Hook. f.

1. Female plant (*Petrie 1147*, NY). 2. A part of female inflorescence (*Petrie 1147*, NY). 3. Floral diagram of female flower. 4. Male plant (*Petrie*, no number, UC). 5. A part of male inflorescence (*Petrie*, no number, UC). 6. Floral diagram of male flower. 7. Male flowers of an inflorescence bearing rudimentary carpels (*Kirk*, no number, G). 8. Floral diagram of a pseudo-bisexual flower (*Kirk*, no number, G.)



TEXT-FIG. IX. *Ascarina rubricaulis* Solms.

1. Female plant (Schlechter 14865, K). 2. A part of female inflorescence (Vieillard 1212, G). 3. Female flower (Vieillard 1212, G). 4. Floral diagram of female flower. 5. Fruit (White 2000, A). 6. Endocarp (White 2000, A).

STUDIES ON THE NUCLEAR APPARATUS OF PERITRICHOUS CILIATES

PART I. THE NUCLEAR APPARATUS OF *EPISTYLIS ARTICULATA* (FROM.)

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INTRODUCTION.

The cytology of Peritrichous ciliates offers many points of interest. In addition to the differentiation of their nuclear apparatus into a macronucleus and a micronucleus as in other Euciliata, they show some special features. The differentiation of the conjugating animals into the larger macro- and smaller micro-conjugant, the difference in the number of micronuclear divisions in the two, the behaviour of the macronucleus during conjugation, the final fusion of the two conjugants to produce the synconjugant, the formation of a single synkaryon, the differentiation of the synkaryon products into the definitive nuclear anlagen and the distribution of the cytoplasmic and nuclear nucleic acids all offer points of special interest on which studies are called for. Recent accounts of the behaviour of the nuclear apparatus during conjugation in the Peritricha (Finley, 1943, Colwin,

1944 and Willis, 1948) while adding to our knowledge of the life history of these ciliates, fail to assess the importance of these findings against cytogenetic background. Willis's work, published in 1948, ignores a great amount of cytological literature on ciliates and is in many respects erroneous.

Older studies on Peritrichous ciliates are numerous. Many of them are of mere historical interest but those of Engelmann (1876), Enriques (1907), Popoff (1908), Penard (1922), Diller (1928), Furssenko (1929) and Pandnos (1939) have contributed materially to our understanding of the behaviour of the nuclear apparatus of the Peritricha. It was felt, however, that there was a necessity to interpret the findings in the light of modern work on the cytology, cytogenetics and cytochemistry of these animals and a study of the locally occurring Peritricha was therefore undertaken. A previous paper by Seshachar and Dass (1951) discusses some of these problems in *Vorticella convallaria*. The present one is devoted to the study of the nuclear phenomena in *Epistylis articulata*.

MATERIAL AND METHODS.

The colonies of *E. articulata* are found attached to weeds and rocks in running sewage water. Recent work of Pillai and collaborators (1942) has shown that among the dominant organisms met with, when raw sewage is aerated, are peritrichous ciliates of the genera *Vorticella*, *Epistylis*, *Carchesium* and *Zoothamnium*. This fact was made use of in obtaining large supplies of material. The material was collected from the flowing sewage waters about six miles out of Bangalore and while some of it was fixed on the spot, large amounts were brought back to the laboratory for further examination and treatment. The material was available abundantly at all times of the year and since examination showed all stages of vegetative growth and conjugation, no special attempts were made to induce conjugation in the laboratory.

The material was fixed in hot Schaudinn's, Bouin's and Carnoy's fluids and was stained in haematoxylin, Feulgen-light green, toluidine blue and Unna's methyl green-pyronin mixture. While whole colonies were treated in the fixing fluids, stained and mounted entire, sections were also cut and stained by the above methods.

OBSERVATIONS.

The vegetative individual—

The nuclear apparatus of the vegetative animal is made of large C-shaped macronucleus and a small spherical micronucleus. The macronucleus stains intensely with Feulgen and other nuclear dyes. The micronucleus does not get stained as intensely. In young animals the macronucleus presents a homogenous appearance and seems filled with fine granules. As the animals grow older, there appear in the macronucleus a number of bodies which, at first small, become larger later. In Feulgen preparations they are seen as unstained and clear spaces (Pl. XVIII, Fig. 3) in the macronucleus but in the haematoxylin preparations, they appear as large deeply stained bodies (Pl. XVIII, Fig. 2). They often show a tendency to run together and present an appearance of canals extending over a great length of the macronucleus. They have been seen in *Trichodina* sp. (Diller, 1928), *V. microstoma* (Finley, 1943), *Urceolaria synaptae* (?) (Colwin, 1944) and *Lagenophrys tattersalli* (Willis, 1948). Finley calls them nucleoli.

The micronucleus, on the other hand, is uniformly stained and is generally fainter in Feulgen and other preparations.

Binary fission—

Two types of binary fission have been observed, differing mainly in the behaviour of the macronucleus. It is now clearly established that the division of

the micronucleus in ciliates is by mitosis and that of the macronucleus by amitosis. The micronucleus initiates the division and is followed later by the division of the macronucleus.

In the first type of division, the macronucleus remaining as a long body, stretches right across the cell and the plane of division (Pl. XVIII, Fig. 4). When the cytosome divides by a furrow beginning at the oral end, it constricts and cuts the stretched macronucleus into two approximately equal parts. In the second type, the macronucleus loses its characteristic C-shape and becomes condensed into a massive polymorphic body (Pl. XVIII, Fig. 5). It is seen to throw off a number of fine filamentar processes into the cytoplasm and by the time the micronuclear division is complete it becomes constricted into two smaller condensed masses which become distributed between the daughter cells. Later they are drawn out into the characteristic C-shape. There does not seem to be any regularity in the occurrence of these two types of fissions. Both occur in the same colony and often, in nearly related members. I am unable to account for this difference or assess its significance.

Micronuclear variation—

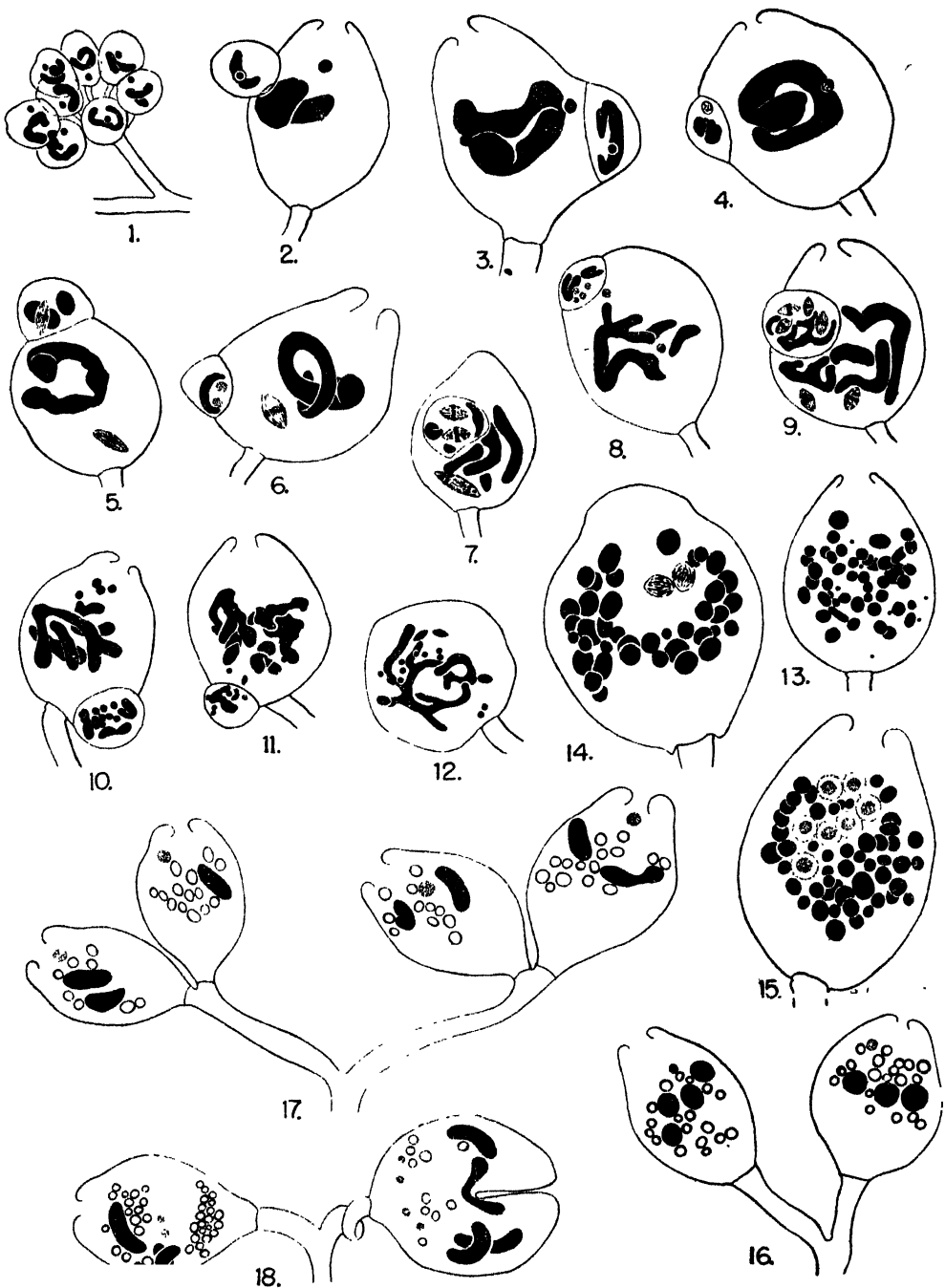
One meets quite frequently, in mass cultures that I have been examining, individuals with two (Pl. XVIII, Fig. 6) or even three micronuclei (Pl. XVIII, Fig. 7) instead of the single one characteristic of the species. Apart from their origin which will be explained in a later section, their future behaviour indicates that once bimicro-nuclearity is introduced, it becomes perpetuated in a colony, both nuclei dividing by mitosis. Even microconjugants with two micronuclei are often noticed and it is likely that the phenomenon persists in these strains for a long time, if not permanently. In two instances trimicronucleate individuals were also noticed. They also tended to reproduce their like, though, by their comparative uncommonness, it must be concluded that this is a rare phenomenon.

Conjugation—

The process of conjugation can be divided into a number of phases: (a) formation of conjugants, (b) fusion of conjugants and synkaryon formation, (c) formation of the nuclear anlagen and (d) reorganization fissions.

(a) Formation of conjugants.

The Peritricha are characterized by a differentiation of the conjugants into a large macro- and smaller microconjugants. Eight microconjugants are produced by the vegetative individual by three quick successive divisions, all seen attached to a stalk (Text-fig. I, Fig. 1 and Pl. XVIII, Fig. 8). Soon each microconjugant develops a telotroch and swims away. The formation of the macroconjugant does not involve any division process. It is merely the vegetative individual that is ready for conjugation. One notices no morphological peculiarities in an animal about to become a macroconjugant. There is some reason to believe that the microconjugants are produced in the colony earlier than the macroconjugants, as reported by Engelmann (1876). I have come across colonies with a large number of microconjugants but with no conjugation process in evidence. The physiological change that transforms a vegetative individual to a macroconjugant must take place long after the production of considerable number of microconjugants. And whatever the nature of this change it also seems to affect large numbers of individuals, for when conjugation is on, one sees enormous numbers in a colony in its grip.



TEXT-FIG. I—(For Explanation, see foot of next page.)

(b) *Fusion of the conjugants and synkaryon formation.*

When the microconjugant comes in contact with the macroconjugant, it spins on its surface for a while and attaches firmly (Text-fig. I, Fig. 3). The position on the body of the macroconjugant where it attaches itself is highly variable and perhaps the entire surface of the body is receptive to it. But the most common site of fusion is at the base, on either side of the stalk.

More than one microconjugant is often seen in association with a macroconjugant (Pl. XVIII, Fig. 10) and though it has not been possible to follow the details of the later processes, it does seem clear that the preliminary nuclear divisions take place in both the microconjugants as well as in the macroconjugant.

The nuclear changes in the two conjugants can be treated under the two heads, (i) the micronucleus, and (ii) the macronucleus.

(i) *The micronucleus.*—Once the microconjugant is firmly attached, changes occur in the nuclei of the two conjugants. The micronucleus of each conjugant starts division (Text-fig. I, Fig. 4) almost simultaneously and the first division spindle is seen (Text-fig. I, Fig. 5). But soon after this the division of the micronucleus in the macroconjugant lags behind while that in the microconjugant proceeds apace (Text-fig. I, Figs. 6 and 7). The result is that by the time the first

EXPLANATION OF TEXT-FIGURE I.

(Figure on previous page.)

- FIG. 1. Bunch of microconjugants. $\times 523$. Feulgen-Light green.
- „ 2. Conjugation. The microconjugant has just come in contact with macroconjugant. $\times 706$. Feulgen-Light green.
- „ 3. Conjugation. The microconjugant is firmly attached to macroconjugant. $\times 706$. Feulgen-Light green.
- „ 4. Conjugation. The micronucleus of both the micro- and macroconjugants in prophase. $\times 706$. Feulgen-Light green.
- „ 5. Conjugation. The micronucleus of both conjugants in metaphase of first division. $\times 706$. Feulgen-Light green.
- „ 6. Conjugation. First progamic division complete in microconjugant, while it is still in metaphase in macroconjugant. $\times 706$. Feulgen-Light green.
- „ 7. Conjugation. The second progamic division in progress in microconjugant. The micronucleus of macroconjugant in anaphase of first division. The macronucleus of both conjugants showing incipient skein. $\times 706$. Feulgen-Light green.
- „ 8. Conjugation. Second progamic division complete in microconjugant and first complete in the macroconjugant. Macronucleus of macroconjugant showing pronounced skein. $\times 706$. Feulgen-Light green.
- „ 9. Conjugation. The third progamic division in microconjugant and second in macroconjugant in progress. $\times 706$. Feulgen-Light green.
- „ 10. Conjugation. Progamic divisions are complete in both conjugants. There are eight nuclei in microconjugant and four in macroconjugant. $\times 706$. Feulgen-Light green.
- „ 11. Conjugation. Same as above. The pronucleus in each conjugant differentiated. $\times 706$. Feulgen-Light green.
- „ 12. Synconjugant. Pronuclei about to fuse. Residual progamic nuclei are still present. $\times 706$. Feulgen-Light green.
- „ 13. Synconjugant. Synkaryon formed. Progamic nuclei gradually disappearing. The macronucleus of the conjugants completely fragmented. $\times 706$. Feulgen-Light green.
- „ 14. Synconjugant. Second metagamic division in progress. Macronuclear fragments solid. $\times 1246$. Feulgen-Light green.
- „ 15. Synconjugant. Metagamic divisions complete. Seven of them have differentiated into macronuclear anlagen. The other is the micronuclear anlage. $\times 1246$. Feulgen-Light green.
- „ 16. F_1 individuals. The vacuole in the fragments increasing in size. Three macronuclear anlagen in one and four in the other. $\times 523$. Feulgen-Light green.
- „ 17. F_2 individuals. Macronuclear anlagen deeply stained. The fragments few in number and ring-like. $\times 523$. Feulgen-Light green.
- „ 18. F_1 individuals. An aberrant condition. In one, only two macronuclear anlagen present. In the other, while three have segregated, the fourth is being cut into two. Two micronuclei present in both individuals. $\times 523$. Feulgen-Light green.

two divisions are completed in the microconjugant, only one is done in the macroconjugant (Text-fig. I, Fig. 8). The next division occurs about the same time in both (Text-fig. I, Fig. 9) with the result the micronucleus in the microconjugant has passed through three divisions and has produced eight progamic nuclei while that in the macroconjugant has produced only four nuclei as a result of two divisions (Text-fig. I, Fig. 10). I am convinced that this difference in the rate of division of the micronucleus and its products refers particularly to the early divisions.

(ii) *The macronucleus.*—The beginnings of the division of the micronucleus bring attendant changes in the macronucleus of each conjugant but the manner of these changes is different in the two. The macronucleus of the macroconjugant elongates and is thrown into a branching skein filling a considerable part of the cell (Pl. XVIII, Fig. 9). Later, when the micronuclear divisions are complete and the four nuclei are produced, the macronuclear skein breaks up into a number of discrete bodies. At first elongated or oval, these bodies finally assume a spherical form filling up the cytosome of the macroconjugant. The macronucleus of the microconjugant which is smaller than that of the macroconjugant just breaks up into a number of spherical bodies, skein formation not being seen in it. The boundary between the two conjugants is lost and the microconjugant is incorporated into the body of the macroconjugant, which henceforth is termed synconjugant.

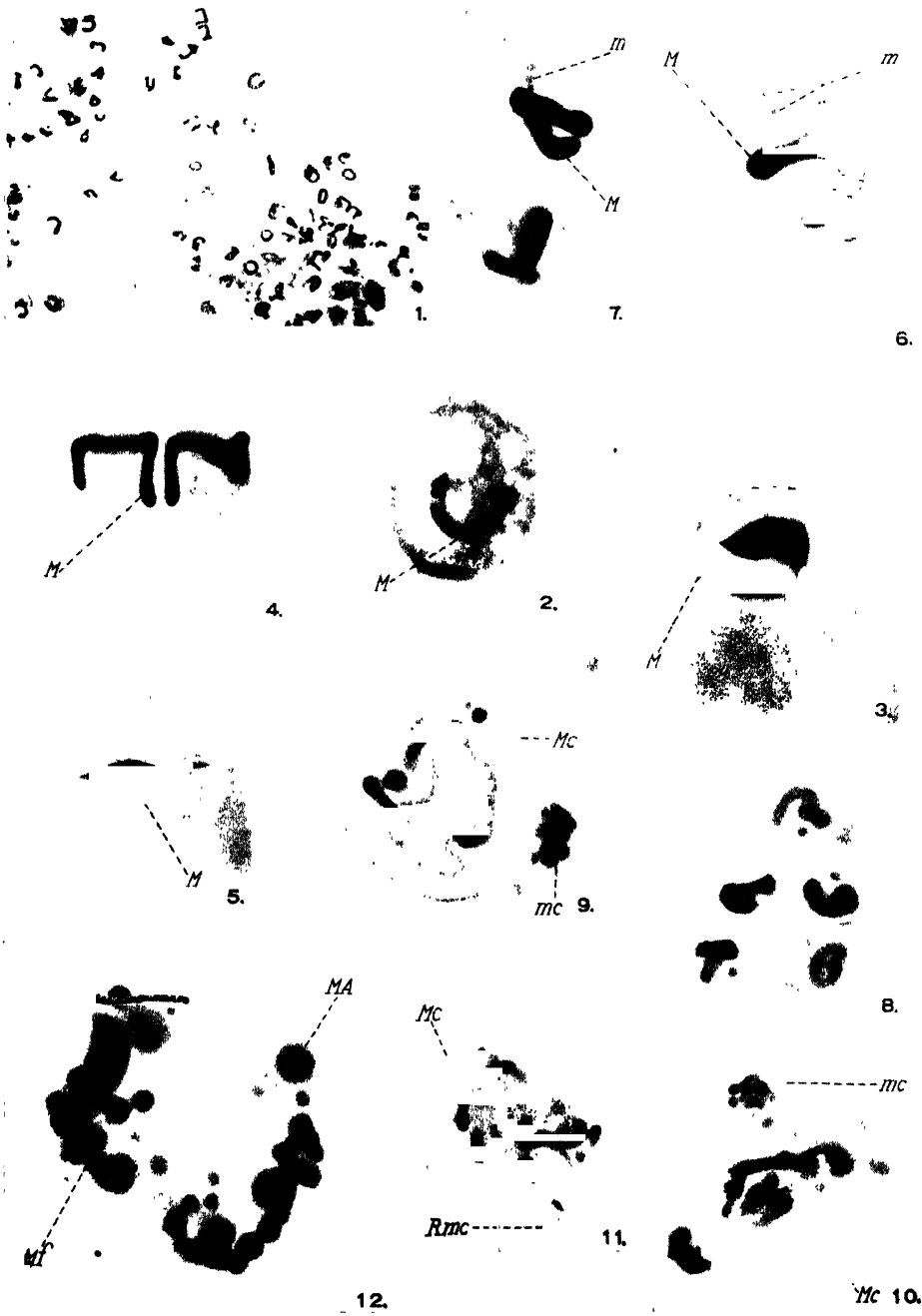
Before the fusion of the cytosomes of the two conjugants the eight progamic nuclei of the micro- and the four of the macroconjugant are seen as small deeply staining spherical bodies which can easily be differentiated from the macronuclear fragments. But soon, one of the division products in each conjugant becomes slightly elongated or spindle shaped (Text-fig. I, Figs. 11 and 12) and becomes paler. This can be identified as the pronucleus and remains in striking contrast with the intensely staining residual progamic nuclei which gradually become smaller and fade away. The fusion of the pronuclei takes place almost immediately after the boundary between the two conjugants breaks down and in the earliest synconjugant, the pale large and spherical synkaryon can be easily differentiated from the many nuclear bodies that literally fill the cytosome, from the unused progamic nuclei and from the macronuclear fragments of both the conjugants. The residual progamic nuclei of which ten can be easily counted at this stage (for two have contributed to the formation of the synkaryon) are intensely staining homogenous bodies, each about 1.5μ in diameter. The macronuclear fragments, on the other hand, are granular in appearance, and with a diameter range between 2.0μ – 6.0μ , can be easily distinguished from the progamic nuclei. The synkaryon, soon after its formation, enlarges and is a pale body in which the faintest indications of a granular and network-like structure can be made out (Text-fig. I, Fig. 13).

(c) *Formation of the nuclear anlagen.*

The synkaryon divides rapidly three times producing eight nuclei, sharing the faintly staining network-like appearance of the parent, but smaller in size (Text-fig. I, Figs. 14 and 15). They are, in the earliest stage discernible, about 4μ in diameter. Seven of them soon enlarge reaching a maximum of 24 – 26μ in diameter while the eighth undergoes a diminution in size to 2.5 – 3μ . The seven enlarged nuclei are the macronuclear anlagen while the eighth gives rise to the micronucleus. Throughout these divisions the anlagen remain large pale bodies which at first give a faint reaction to Feulgen but which progressively become deeper.

(d) *Reorganization divisions.*

As the macronuclear anlagen reach their maximum size, the synconjugant prepares for division. The fragments of the old macronuclei (of the two conjugants) which were intermingled with the macronuclear anlagen now separate from them



and aggregate at the base of the cell near the insertion of the stalk (Pl. XIX, Fig. 1). This leaves the seven macronuclear anlagen and the micronucleus free in the cytoplasm more anteriorly. The micronucleus divides by mitosis and the products separate, occupying the two sides of the body. The division furrow starts from the oral end and the macronuclear anlagen which by now are quite clear, separate into two groups of four and three which the deepening furrow segregates into two individuals (Text-fig. I, Fig. 16; Pl. XIX, Figs. 2 and 3). The fragments are also segregated between the daughter cells of the first reorganization fission so that each comes to possess an approximately equal number of them. While this is the most common and the normal method of segregation of the macronuclear anlagen, stray instances occur where the segregation of the macronuclear anlagen is six and one at the first fission.

The second reorganization fission follows soon after and the four individuals at the end of it have 2 : 2 : 2 : 1 anlagen (Text-fig. I, Fig. 17; Pl. XIX, Figs. 4a and b.) The third division restores the normal macronuclear equipment to its products (Pl. XIX, Fig. 5).

During the later reorganization fissions, the macronuclear anlagen become elongated and develop clear spaces in them (in Feulgen preparations). The fragments continue to become distributed throughout the divisions and one often finds even in individuals where the normal nuclear complement has been restored, a few faintly staining but unmistakably clear fragments in the cytoplasm.

(e) *Macronuclear fragments.*

It was observed that with the incorporation of the microconjugant with the macroconjugant and the merging of the macronuclear fragments of the two, the number of these fragments in the now synconjugant reach often a high figure. I have counted as many as a hundred fragments literally choking the cytoplasm of the synconjugant in some cases. In the early stages these are deeply staining uniform bodies, but as the new macronuclear anlagen enlarge, in each of the fragments there arises a Feulgen negative space (Pl. XVIII, Fig. 12). This is very small in the beginning but by the time the macronuclear anlagen have reached their maximum size and the synconjugant prepares for its first division, each fragment has become hollow sphere, with a central clear space which is negative to Feulgen and peripheral rim which is positive to it (Text-fig. I, Fig. 17). This progressive 'vacuolation' of the fragments proceeds through the reorganization fissions by the end of which each is a faint ring-like body (Text-fig. I, Fig. 17; Pl. XIX, Fig. 5). There is a progressive loss of staining power too of the peripheral regions, through the reorganization fissions, so that at the end, the fragments look like very faint rings. Soon they cease to pick up the stain and are lost to view altogether. This change in the macronuclear fragments is one of the most striking phenomena met with during conjugation and reorganization fissions in *E. articulata* with unfailing regularity and constancy.

DISCUSSION.

1. *Nuclear apparatus:*

The nuclear apparatus is typical of the order Peritricha, the macronucleus is large and C-shaped while the micronucleus is spherical. Cross-sections of the macronucleus show it as a cylinder and so the reference to it as 'band shaped', indicating a flattening, is wrong. It is best described as an elongated and curved cylinder.

Feulgen negative spaces in the macronucleus are seen regularly, especially in organisms which have just been produced by the reorganization fissions and those which are at the height of their trophic activity. They sometimes grow so numerous that they coalesce to form longitudinally running canals in the macronucleus.

In haematoxylin and toluidine blue preparations, however, they are deeply stained bodies. They have been recorded, among the peritricha in *Trichodina* (Diller, 1928), *Zoothamnium alternans* (Fauré-Fremiet, 1930), *Vorticella microstoma* (Finley, 1943), *Urceolaria synaptae* (?) (Colwin, 1944) and *Lagenophrys tattersalli* (Willis, 1948). Finley (1948) who has made a detailed study of them in *V. microstoma* refers to them as 'Nucleoli' and says they open into the cytoplasm to discharge their contents. Fauré-Fremiet (1930) found this Feulgen negative material in these spaces of the macronucleus, refringent. The precise nature of these spaces and the material that fills them is still to be determined and cytochemical studies are planned for this purpose.

The occurrence of bimicronucleate animals in a natural population of Peritrichous ciliates has never been recorded. However, Diller (1940) reported their occurrence in *Paramecium caudatum* and considered them as abnormalities brought about as a result of a variation in the distribution of the nuclear products during binary fission. In *E. articulata* great numbers of bimicronucleate animals turn up in some colonies and the condition apparently lasts for a considerable time, binary fission of such organisms affecting the division of both the micronuclei. In such colonies, even microconjugants are bimicronucleate. But it has not been possible to follow the course of conjugation involving bimicronucleate animals.

A suggestion may perhaps be offered in regard to the origin of bimicronucleate animals. It was observed that after conjugation the divisions of the synkaryon result in the production of eight nuclei of which seven are the macronuclear anlagen and one the micronucleus. It has been noticed occasionally that six of the eight nuclei enlarge to give rise to the macronuclear anlagen and two become the micronuclei (Text-fig. I, Fig. 18). Later reorganization fissions show that the bimicronucleate condition is perpetuated while the lack of one macronuclear anlage is made good by the splitting of one of the anlagen instead of their segregation. It is possible that this is at least one of the methods of the production of bimicronucleate forms in *E. articulata*.

2. Binary fissions:

The behaviour of the macronucleus during binary fission has already been recorded. On this basis, it is noticed we can distinguish two types of fission, one, where the macronucleus does not lose its characteristic form but which constricts into two parts, and the other, where it becomes consolidated into a dense mass which throws out a number of filamentar processes into the cytoplasm, before it becomes divided. In both cases the division is by amitosis but the point of interest appears to lie in the thread-like processes given off by the macronucleus into the cytoplasm during division of the second type. These processes are often quite numerous and recall the similar processes given off from the peritrichous macronucleus of the silk-gland cells of the larva of the silk-worm moth. It is this striking similarity too that makes me put forth the suggestion that they might be associated, as in the silk-gland cell, with rapid protein synthesis. It is of course, too premature to speak conclusively on the significance of this striking phenomenon and it is expected that precise cytochemical and enzyme studies will reveal the true nature of these nuclear processes. It has been repeatedly asserted that the macronucleus in ciliates concerns with the day-to-day metabolic activities of the cell but proof as to the precise nature of this functioning is still to be provided.

3. Conjugation:

The process of conjugation in Peritricha is characterized by a number of interesting phenomena:

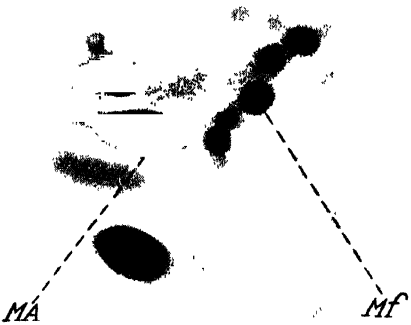
- (a) The difference in size between the conjugating animals.
- (b) The complete fusion of the conjugants after the process.



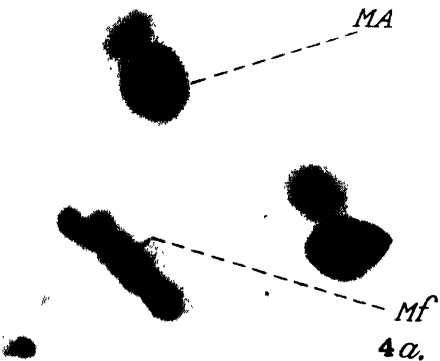
1.



2.



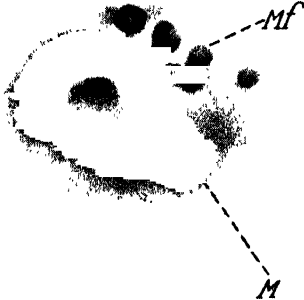
3.



4a.



4b.



5.

- (c) The difference in the number of progamic divisions in the micronucleus and the status of the pronuclei.
- (d) The formation of the nuclear anlagen.

(a) *Size of conjugants :*

The Peritricha as a rule are characterized by dissimilar conjugants. The macroconjugant is merely a vegetative individual occupying certain regions of the colony as *Zoothamnium arbuscula* (Furssenko, 1929), *Z. alternans* (Summers, 1938), *Carchesium polypinum* (Popoff, 1908) and *Ophridium versatile* (Kaltenbach, 1916) or is produced as a result of a 'sex-differentiating' division as in *Opercularia coarctata* (Enriques, 1907) or preconjugation division as in *V. microstoma* (Finley, 1943) and *Lagenophrys* sp. (Awerinzew, 1912). In *E. articulata* it does not show any difference from the vegetative individual, either in its position in the colony or in its size and morphology. From my examination of large numbers of colonies of this species, I am inclined to think, whatever the change that makes a vegetative animal into a macroconjugant must be physiological and beyond detection under the microscope.

The microconjugant is much smaller. Finley (1943) cites three methods of microconjugant formation in the Peritricha:—(1) two or three rapid divisions of a vegetative individual, (2) unequal division of vegetative individual, the smaller of the two becoming the microconjugant, and (3) metamorphosis of a microzooid. A recent paper by Willis (1948) cites a new method of microconjugant formation in *Lagenophrys tattersalli*. In this species the vegetative animal divides unequally to give rise to two individuals. The smaller (called the protoconjugant) again divides to give rise to two similar microconjugants. Evidently the condition in *L. tattersalli* is a slight modification of, and can be derived from, the second method which also obtains in other species of *Lagenophrys* (Awerinzew, 1912; Penard, 1922).

The condition in *E. articulata*, however, comes under the first method. Here, as already observed, the vegetative organism divides quickly thrice producing eight small individuals which move away and become microconjugants. This type of microconjugant formation has been reported in other species of Epistylis also, e.g., *E. plicatilis* (Claparède and Lachmann, 1858–61, Engelmann, 1876) and *E. simulans* (Plate, 1888).

In consonance with difference in the size of the conjugating animals, there is a size difference in the macronucleus which is much larger in the macroconjugant, but not in the micronucleus which in both conjugants is about 3μ .

(b) *Fusion of conjugants :*

The Peritrichous ciliates are also characterized by a complete fusion of the two conjugants and this has raised doubt whether the process can be called 'conjugation'. In all ciliates outside the order Peritricha, the two conjugants which are more or less similar in size separate after nuclear exchange and are able to lead independent lives. In the Peritricha, on the other hand, the microconjugant is much smaller and sooner or later during the process it completely fuses with the macroconjugant. Associated with this size difference is also a difference in the behaviour and activity of the two conjugants, of which the larger macroconjugant is stalked and inactive, while the smaller microconjugant is free and motile. An analogy has been established between the conjugating animals of Peritrichous ciliates and the fusing gametes in the Metazoa and Willis (1948) goes so far as to say that in this group the process should be termed 'copulation' and not 'conjugation'. Whatever the terminology used, it seems clear that the condition in the Peritricha can be derived from that in other ciliates. Noland's (1927) work on *Metopus signoides* clearly indicates that in this spirotrichous ciliate, there is no true reciprocal fusion, the pronuclei migrating into one of the animals in which fusion takes place. The other individual, bereft of its nuclei, becomes a small residual structure which ultimately dies. Moreover, no reciprocal fusion of the nuclei takes place in that only one synkaryon is formed instead of the two characteristic of the

majority of ciliates outside Peritricha. Apparently the phenomenon found in Peritricha is foreshadowed in animals like *Metopus*. The condition in *Zoothamnium arbuscula*, as described by Furssenko (1929), approximates to that of *Metopus* in that unlike other peritrichous ciliates, nuclear exchange between the macro- and microconjugant occurs, but only the macroconjugant survives. Cases similar to that of *Zoothamnium* occur in other Peritricha, particularly in *V. microstoma* where Finley (1943) has reported the distinctness of the microconjugant though it ultimately dies.

In this connection the case of *E. articulata* is interesting. In this ciliate, normally the microconjugant becomes completely merged with the macroconjugant and only one synkaryon (that in the macroconjugant) is produced. But occasionally one meets with a small residual microconjugant sticking on the synconjugant, apparently after its pronucleus has moved into the macroconjugant, and in the process of degeneration (Pl. XVIII, Fig. 11). This anomalous situation that exists here, occurs more frequently in *Z. arbuscula* among Peritricha and *Metopus sigmoides* in other ciliates, thereby establishing a series of intermediate gradations between conjugation as it occurs in ciliates other than Peritricha, and conjugation as it occurs in Peritricha.

(c) Micronuclear divisions :

In all euciliates where conjugation has been studied, except in members of the order Peritricha, the micronucleus of each conjugant undergoes three progamic divisions. Often, the third division affects only one of the second division products; the other three degenerate. The pronuclei are products of the third division. In Peritricha, however, the condition is different. In members of this order, the micronucleus of the microconjugant undergoes three divisions, producing eight nuclei while that of the macroconjugant divides only twice, giving rise to four nuclei. However, in *Trichodina sphaeroidesi*, Pandnos and Nigrelli (1942) reported an equal number of divisions in the micronucleus of both conjugants. In *Urceolaria synaptae* (?) also, Colwin (1944) has described three divisions in the micronucleus of both conjugants. The same condition obtains in *Z. arbuscula* (Furssenko, 1929). Apart from these instances all Peritricha are characterized by a dissimilarity in the number of micronuclear divisions, there being three in the microconjugant and two in the macroconjugant.

In regard to the homology of these divisions of the two conjugants, however, there is considerable difference of opinion. It has been stated, on genetical grounds, that in most ciliates, the second of the three progamic divisions is reduction division (Sonneborn, 1947). In regard to the Peritricha, however, the position is a little confusing, because here the occurrence of two divisions in the macroconjugant and three in the microconjugant raises two problems:—(1) which of the two divisions of the microconjugant is homologous with the two divisions of the macroconjugant? (2) which is the reduction division in each of the two conjugants

A detailed analysis of the divisions of the two conjugants in *E. articulata* shows that unlike most Peritricha, and especially *V. microstoma* described by Finley (1943), the micronuclei in both conjugants start their first division simultaneously. Finley reports a preliminary division in the micronucleus of the microconjugant 'before the two conjugants are firmly united'. This is not true of *E. articulata* where the divisions of the micronucleus start only after the two conjugants are firmly united. The first division in the two conjugants not only starts synchronously but also reaches metaphase at the same time. Large numbers of conjugating pairs where the nuclei are in metaphase I in both conjugants are seen in my material. From this stage onwards, the divisions in the two conjugants are out of step and a lagging in the macroconjugant is noticeable. While the micronucleus in the macroconjugant remains at metaphase, that in the microconjugant proceeds and not until the metaphase of the second division in the microconjugant does the division in the macroconjugant proceed further. From now on, the divisions proceed again more

or less synchronously so that by the time three divisions are completed in the microconjugant only two are finished in the macroconjugant. The sequence of events are expressed in the diagram. (Text-fig. II, A-I.)

The question of the homology of the divisions can be taken up now. Finley (1943) argues, on the fact that a division has been completed in the microconjugant by the time the conjugants are firmly united, and also on the ground of a morphological similarity between the prophase of the microconjugant's second and macroconjugant's first division that it is first division of the microconjugant that is 'extra' and that the two divisions in the macroconjugant correspond to the last two divisions in the microconjugant. In *E. articulata* there is no preliminary division of the kind in *V. microstoma* and there is no characteristic difference between one progamic prophase and another as in this organism. Of the three divisions in the microconjugant it is the last that shows, from the point of time taken, a complete correspondence with the second division in the macroconjugant, for the second division of the latter and the third in the microconjugant start simultaneously and also complete together. In case of earlier divisions, however, there is a tilt in timing so that by the time one division is complete in the macroconjugant two are finished in the microconjugant. This, taken along with the fact that the first division starts simultaneously in both conjugants, leads me to believe that it is the second division that is 'extra' in the microconjugant in *E. articulata* and the first and third correspond to the two divisions in the macroconjugant.

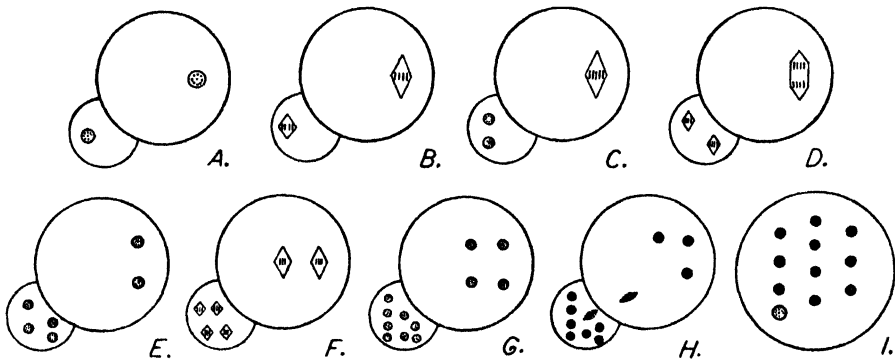


FIG. II.

Diagrammatic representation of the sequence of micronuclear divisions in micro- and macroconjugants. Only the micronucleus and its products are shown.

- FIG. A. The micronucleus in the prophase of first progamic division in both conjugants. Corresponds to Text-fig. I, fig. 4.
 „ B. Division has reached metaphase in both conjugants. Corresponds to Text-fig. I, fig. 5.
 „ C. The first progamic division has been completed in the microconjugant. It is still in metaphase in macroconjugant. Corresponds to Text-fig. I, fig. 6.
 „ D. The second progamic division is in progress in the microconjugant. The first progamic division is in anaphase in the macroconjugant. Corresponds to Text-fig. I, fig. 7.
 „ E. Second progamic division has been completed in the microconjugant. The first progamic division has been completed in the macroconjugant. Corresponds to Text-fig. I, fig. 8.
 „ F. Third progamic division is in progress in the microconjugant. The second progamic division is in progress in the macroconjugant. Corresponds to Text-fig. I, fig. 9.
 „ G. Progamic divisions have been completed in the conjugants. Eight progamic nuclei in the microconjugant and four progamic nuclei in the macroconjugant are seen. Corresponds to Text-fig. I, fig. 10.
 „ H. Pronuclei in each conjugant differentiated. They are spindle shaped. Corresponds to Text-fig. I, fig. 11.
 „ I. Synkaryon formed (stippled). The rest are the residual progamic nuclei. Corresponds to Text-fig. I, fig. 13.

In regard to the second question as to the division where the reduction takes place, cytological observations on chromosome counts have not been possible. Sonneborn (1947) on genetical grounds concludes that in *Paramecium*, of the three progamic divisions in each conjugant, it is one of the first two that is reductional. Genetical experiments of the type conducted in *P. aurelia* have never been done in any peritrichous ciliate but the analogy of *Paramecium* is not likely to be helpful here, for, as observed above, the second division has no parallel in the macroconjugant. That leaves the first or third division in the microconjugant as the possible reducing division. For the third division, it must be said that that is the only one which, in point of duration, is exactly similar in both conjugants. But Sonneborn (1947) argues very convincingly, again on genetical grounds, against regarding the third division as the reduction division. There are very important reasons why it is not necessary to regard the genetics of *Epistylis* to be on the same lines as that of *Paramecium*, the most fundamental of which is the absence of reciprocal fusion of the pronuclei and the emergence of a single synconjugant instead of two separate exconjugants but the evidence offered by the similarity of this division in the two conjugants (the second in the macroconjugant and third in the microconjugant) is so strong that one would be inclined to regard that as the reduction division.

But the possibility of the first being the reduction division cannot altogether be ruled out. And there are interesting parallels between the behaviour of this division and the first meiotic division in the metazoan oocyte. It will be recalled that the first division in the macroconjugant pauses at metaphase until the metaphase of the second division in the microconjugant. From then onwards the divisions become synchronous. The parallelism between this and the course of meiosis in the metazoan egg cell is very striking. It is common knowledge that in a large number of organisms the oocyte initiates the meiotic divisions but is unable to go through them without the stimulus offered by fertilization and entry of the sperm. The pause in the first division of the macroconjugant's micronucleus at metaphase and its subsequent resumption at a later stage suggests a phenomenon of similar nature though it is not possible to detect anything in the nature of the stimulus activating the continuation of the division of the macroconjugant's micronucleus. There, I am afraid, we must leave the problem, until we have more evidence either on cytological or genetical grounds.

(d) Formation of nuclear anlagen :

The interest in the development of the nuclei in the ciliate exconjugant lies in the fact that both the macro- and micronucleus are products of the synkaryon, which, again, has its antecedents in the micronucleus. An explanation for this phenomenon where two such diverse elements as the macro- and micronucleus arise from the two division products of a single fusion nucleus has never been found.

But the details of this process are also of considerable interest. In peritrichous ciliates the single synkaryon of the synconjugant divides three times to give rise to eight products. In the majority of species including *E. articulata* seven of these become macronuclear anlagen and the eighth, the micronucleus. So far as is known, in one species, *Vorticella convallaria* (Seshachar and Dass, 1951) there is a slight departure, in that six become macronuclear anlagen and two the micronuclei.

There is apparently an interesting specificity in this matter. I have occasionally found instances where, due to a reason I am unable to see, there is a slight departure from the normal in the development of the anlagen, and where six instead of seven synkaryon products become macronuclear anlagen and two the micronuclei. It was interesting to follow the fate of such individuals through their reorganization fissions. It was noticed that at the first reorganization fission the segregation of the macronuclear anlagen was such that the two daughters got

four and two macronuclear anlagen respectively and two micronuclei each. The second fission in the individual with four anlagen did not merely segregate the existing anlagen between the daughter cells. It was curious to note that one of the four macronuclear anlagen became constricted and later split into two parts so that the two daughter individuals received three and two anlagen each. The further divisions of these cells were segregative in regard to the macronuclear anlagen. Every one of these products possessed two micronuclei instead of one and probably all the bimicronucleate animals encountered in some colonies in large numbers in this species owe their condition to this slight variation in the development of the nuclear anlagen in the synconjugant.

The significance of this is not clear but it is interesting to note, apart from the bimicronuclearity introduced on account of this mis-step, the behaviour of the macronuclear anlagen. One would have expected the reorganization fissions to be purely segregational in regard to the macronuclear anlagen whether they were originally six or seven. It would merely have meant that six, instead of seven, individuals would result from the reorganization fissions,—at first sight not a great difference. But apparently the matter is of much greater import, for, by a splitting of one of the anlagen, the total number of organisms that result from the reorganization fissions is restored to seven. It would appear that this is a matter of much greater consequence than the production of bimicronuclearity. It would also mean that the differentiation of the synkaryon products into macro- and micronuclear anlagen is not just a unidirectional process of the differentiation of some of these products into the macronuclear anlagen by their enlargement. It would imply a differentiation in the development of the micronucleus too, which is as irreversible as that of the macronucleus.

Finley observes in *V. microstoma* that one of the synkaryon products that is to become the micronucleus shrinks in size while those that are to give rise to the macronuclei enlarge. I have also noted in *E. articulata* such a reduction in size of one of the synkaryon products. At the end of the third meiotic division the eight products are similar and measure $4.0-4.2\mu$ in diameter but soon after, one of them becomes much smaller and in the first division is 2.5μ in diameter while the other seven enlarge. It is not my purpose to imply that the reduction in size is the only manifestation of the differentiation of the micronucleus, but it would seem necessary to emphasize that differentiation is a bidirectional process operative as much in the development of the micronucleus as in that of the macronucleus. And apparently in both cases it is irreversible.

In this connection it would seem necessary to mention the concept developed by Sonneborn (1947) in regard to the constitution of ciliate macronucleus. On genetical grounds he believes that the macronucleus is compound and that it is made up of a number of units, each of which has a diploid component of genes, while the micronucleus is a simple diploid. This would imply that the larger size of the macronucleus is due merely to an increase in the number of these units, each with a full complement of genes and that the size difference between the two nuclei can be explained on the basis of the large number of their component units. If this were so, the failure of the seventh synkaryon product to enlarge and develop into a macronuclear anlage cannot be explained, especially in view of the expedients by which this omission is rectified. The differences seem more fundamental and probably lie in the chemical content of the two nuclei (Seshachar, 1950).

SUMMARY.

The nuclear apparatus of *E. articulata* consists of C-shaped cylindrical macronucleus and a small spherical micronucleus.

During vegetative stage certain Feulgen negative spaces appear in the macronucleus. They have been referred to as 'nucleoli'. In some cases they increase in size and number to form canaliculi.

In addition to the normal unimicronucleate forms some colonies show bimicronucleate individuals which often occur in considerable numbers. Trimicronucleate individuals also occur sometimes.

Two types of binary fission are observed occurring in members of the colony, the criterion of difference being the behaviour of the macronucleus.

Eight microconjugants are produced by three rapid successive divisions of a vegetative individual in the colony. The macroconjugant resembles the vegetative individual.

The microconjugants are produced earlier than the macroconjugants.

Usually the microconjugant attaches itself to the macroconjugant near the base, by the side of the stalk. There is apparently no uniformity in this respect. A microconjugant may attach itself anywhere on the body of the macroconjugant.

Multiple microconjugants may attach themselves to a macroconjugant; all of them undergo nuclear changes.

The micronuclear divisions start simultaneously in both conjugants. The division process pauses in the macroconjugant for some time, but it proceeds unabated in the microconjugant.

The micronucleus of the macroconjugant divides twice, while that of the microconjugant divides thrice; thus four progamic nuclei are produced in macroconjugant and eight in the microconjugant. One of the progamic nuclei in each conjugant is the pronucleus.

The macronucleus in both conjugants fragments. In the macroconjugant the macronucleus is first thrown into an elaborate skein, then fragments into spherical bodies.

The microconjugant merges into the body of the macroconjugant *in toto* to form a synconjugant. In rare cases a residual microconjugant is observed.

Two pronuclei fuse to form a synkaryon. The other progamic nuclei are resorbed into the cytoplasm.

The synkaryon divides thrice successively to form eight metagamic nuclei. At first they are all identical. Of these seven enlarge to form macronuclear anlagen while the other shrinks to form the micronucleus.

Macronuclear anlagen enlarge and then acquire DNA. Three reorganization fissions follow soon after at the end of which each of the eight products has a macronucleus and a micronucleus.

Soon after synkaryon formation each of the macronuclear fragments develops a Feulgen negative space in it. This gradually enlarges through the reorganization fissions until towards the end of fissions, the fragments are in the form of faint ring shaped bodies. They disappear soon.

ACKNOWLEDGEMENT.

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EXPLANATION OF PHOTOMICROGRAPHS.

Key to lettering.—*M* = Macronucleus; *m* = Micronucleus; *Mc* = Macroconjugant; *mc* = Microconjugant; *Rmc* = Residual microconjugant; *MA* = Macronuclear anlagen; *Mf* = Macronuclear fragments.

PLATE XVIII.

- Fig. 1. General picture of the colony. $\times 39$. Feulgen-Light green.
- „ 2. Section of vegetative individual showing deeply stained regions in the macronucleus. $\times 666$. Haematoxylin.
- „ 3. Vegetative individual showing Feulgen negative spaces in the macronucleus. $\times 666$. Feulgen-Light green.
- „ 4. Binary fission Type I. $\times 666$. Feulgen-Light green.
- „ 5. Binary fission Type II, showing the macronuclear processes into the cytoplasm. $\times 1000$. Feulgen-Light green.
- „ 6. Bimicronucleate individual. $\times 666$. Feulgen-Light green.
- „ 7. Trimicronucleate individual. $\times 666$. Feulgen-Light green.
- „ 8. Bunch of microconjugants. $\times 666$. Feulgen-Light green.
- „ 9. Conjugation. The macronuclear skein in the macroconjugant is clear. $\times 666$. Feulgen-Light green.
- „ 10. Conjugation. Macroconjugant with two microconjugants attached. $\times 666$. Feulgen-Light green.
- „ 11. Residual microconjugant attached to the macroconjugant. $\times 666$. Feulgen-Light green.
- „ 12. Synconjugant. The vacuoles are just making their appearance in the macronuclear fragments; macronuclear anlagen still faint. $\times 666$. Feulgen-Light green.

* References marked with asterisks were not available in the original.

PLATE XIX.

- FIG. 1. First reorganization fission. The macronuclear fragments localized at the base. $\times 1000$. Feulgen-Light green.
- „ 2. F1 individual with three macronuclear anlagen. The number of macronuclear fragments has decreased. $\times 1000$. Feulgen-Light green.
- „ 3. F1 individual with four macronuclear anlagen. The vacuole in the fragments has increased in size. $\times 1000$. Feulgen-Light green.
- „ 4a & 4b. Second reorganization fission in progress. $\times 1000$. Feulgen-Light green.
- „ 5. F3 individual. The macronucleus has assumed vegetative form. The fragments are ring-like and few in number. $\times 1000$. Feulgen-Light green.

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EFFECT OF CONCENTRATION ON THE FLUORESCENCE OF DYESTUFF SOLUTIONS

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1. INTRODUCTION.

The investigations on the effects of viscosity and temperature of the medium on the polarisation of the fluorescent light emitted by dyestuff solutions by Tawde and Ramanathan (1952) reveal a remarkable dependence of the polarisation on the concentration of the dyestuff. That the degree of polarisation is a function of concentration has been established by the work of Gaviola and Pringsheim (1924), Weigert and K  ppler (1924), Lewschin (1924), Mitra (1939), Vavilov (1943), and others. While most of the observers found that the degree of polarisation decreased with the concentration of the dyestuff, Weigert and K  ppler noticed an increase in the degree of polarisation with concentration in the case of aqueous solutions of some dyestuffs. Mitra finds that the observed decrease of polarisation with concentration contradicts the results to be expected on the basis of Perrin's theory, which leads to an increase of polarisation with concentration. Since then, Vavilov (1943) and F  rster (1948) have put forward theories of the influence of concentration on the fluorescence of solutions, involving the principles of quantum mechanical resonance. It was, therefore, thought fit to investigate the effect of concentration on the polarisation of fluorescence of solutions of the dyestuffs used in the previous work of the authors, referred to above, and examine the results in the light of the new theories.

2. EXPERIMENTAL.

The experimental arrangements were the same as described in the previous paper (Tawde and Ramanathan, 1952). Monochromatic radiation of either the 5461   or the 4358   was used for excitation as before. The whole range of concentrations was obtained by adding the appropriate volumes of a stock solution of known strength to measured volumes of doubly distilled glycerine preserved free from dust. Tests were performed at all concentrations to see whether the fluorescence or molecular scattering of glycerine had any appreciable influence on the degree of polarisation of the fluorescence of the dyestuff solutions. As this influence was practically nil, the results obtained by direct observation are recorded below. As the percentage of polarisation was never less than 31, the Savart plate method was not used at all. All observations were made at room temperature.

3. RESULTS.

The values of the percentage polarisation P , and the mean lifetime τ of the excited states of the fluorescent molecules at various concentrations, calculated on the basis of Perrin's expression (1929),

$$p = p_0 / \left[1 + \left(1 - \frac{1}{3} p_0 \right) RT\tau / V\eta \right]$$

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are entered in Table 1. In this relation, p is the degree of polarisation and τ is the mean lifetime under a given set of conditions, p_0 is the maximum value of p , R is the gas constant, T is the absolute temperature of the solution, V is the grammolecular volume of the dyestuff and η is the viscosity of the medium.

TABLE 1.

Values of percentage polarisation and mean lifetime ($\times 10^8$) sec.

Exciting λ : 4358 Å for Acridine Orange, 5461 Å for others.

Temperature: 27.5°C.; Viscosity: 7.64 poises.

Concentration $\times 10^5$ g./cm. ³	A.O.		S		A		T	
	P	τ	P	τ	P	τ	P	τ
16	31	10	38	9	..	..	33	8
12	34	7	..	..	..	..	36	6
8	37	5	43	4	31	18	40	4
6	..	..	..	..	34	15	..	..
4	39	3	46	2	38	9	..	..
3	..	..	..	..	41	7	45	2
2	43	1.5	49	..	43.5	5	47	1
1	44	..	..	..	46	3	48	..
0.8	45	..	..	..	47	1.9	..	..
0.6	..	..	..	..	48	..	..	..
0.52	45	..	..	..	..	..	..	..
0.48	..	..	50	..	..	..	..	..
0.4	..	..	..	..	49	..	..	..
0.24	45	..	50	..	..	..	..	..
0.2	..	..	..	..	50	..	49	..
0.12	45	..	..	..	50	..	..	..
0.08	..	..	50	..	..	..	50	..
0.04	..	..	..	..	..	..	50	..

A.O.: Acridine Orange R; S: Safraninc 6B; A: Aurophenino O; T: Thioflavine T.

4. DISCUSSION AND CONCLUSIONS.

The results indicate that the degree of polarisation decreases with concentration of the dyestuff. In each case, at low concentrations, the polarisation reaches a maximum. The values of the maxima agree with those obtained by Tawde and Ramanathan (1952) at low temperatures or high viscosities. In all the cases, the mean lifetime of excited states increases with the concentration of the dyestuff.

(i) Polarisation and Concentration—

The theory put forward by Vavilov (1943) leads to the expression:

$$1/P = (1/P_0) [1 + c\beta(1-p)]$$

where, P is the degree of polarisation at a concentration c of the dyestuff, P_0 is the maximum value of P (when $c \rightarrow 0$), $\beta = \frac{\tau_0}{K}$, τ_0 being the maximum value of the mean lifetime, K is a structural constant and p is the ratio of the degree of polarisation after the first transfer of excitational energy to P_0 .

On the basis of this theory, the observed decrease of polarisation with concentration means that the number of transfers of excitation energy before the final emission of the fluorescent light, also increases with the concentration. The polarisation attains a maximum value at a particular concentration and this value remains the same for any further increase in concentration. This can be interpreted by assigning a 'distance of action' to the fluorescent molecules. The excitation energy of a given molecule cannot be transferred to a neighbouring molecule if it is beyond the distance of action. It is obvious that, as the concentration of the dyestuff is decreased, a stage is reached when no molecule of the dyestuff is within the distance of action of any other dye molecule. In these circumstances, an excited molecule can lose its energy only by way of emission of light. The conditions are not altered when the concentration is decreased still further and the polarisation remains at its maximum value. In order to know the nature of the interaction between the dye molecules, it is necessary to consider the mean lifetime of excited states of the molecules.

(ii) *Mean Lifetime and Concentration.*—

To discuss the implications of the increase of the mean lifetime with concentration found in section 3, the equation $\tau_1/\tau_2 = I_1/I_2$, already quoted by Tawde and Ramanathan (1952) is useful. Here, I_1 , τ_1 , I_2 , τ_2 , are the intensities of fluorescence and mean lifetimes under two different conditions. This relation indicates an increase in intensity of fluorescence with concentration. Such an increase is possible at low concentrations of the dyestuff. Starting with zero concentration when there can be no fluorescent light at all, as the concentration is increased, the number of excited molecules will also increase and since at very low concentrations, the probability of dissipation of excitation energy in channels other than the emission of light is very small, the intensity of the fluorescent light is bound to increase. However, this increase in intensity will take place only up to a particular concentration because, a stage will be reached, when the probability of deactivation of the activated molecules by processes other than that of emission of light will become significant, and this probability of deactivation may also increase, on further increase of concentration. One could, therefore, expect a decrease of intensity above this optimum concentration.

Hence, it is of importance to decide whether the concentrations used in our experiments lie below or above this optimum concentration. For this purpose, the formulae given by Förster (1948) are helpful. They are:

$$(1) \ n_1 = n \frac{1 + \tau F}{1 + 2\tau F}, \text{ where } n_1 \text{ is the probability of emission of light by the}$$

primary molecule which absorbs the incident energy, n is the quantum yield of fluorescence, τ is the mean lifetime of excited states of the dye molecule and F is the number of transfers of excitation energy per unit time from the primary molecule which absorbs the incident energy, to a neighbouring molecule.

(2) $p/p_{\max.} = (6n_1/n)/(5 + n_1/n)$, where p and $p_{\max.}$ are the values of the degree of polarisation of the fluorescent light under given conditions and its maximum value and n_1 , n have the same meaning as in (1) above.

It was possible to calculate the values of τF for the different concentrations by using the values of p and $p_{\max.}$ of section 3. These values are given in Table 2. Values corresponding to concentrations below 1×10^{-5} g./cm.³ are not given as the polarisation practically attains its maximum value.

It follows that practically no transfer of excitation energy takes place from the primary molecule and that a molecule which absorbs the incident energy re-emits it as fluorescent light. Therefore, at the concentrations used in our experiments, each molecule of the dyestuff retains its individuality and for all purposes behaves in an isolated manner. Our concentration range corresponds,

TABLE 2.

Values of τF .

Concentration $\times 10^5$ g./cm. ³	16	12	8	6	4	3	2	1
Acridine Orange R ..	1.1	0.64	0.33	..	0.18	..	0.1	0.06
Safranine 6B ..	0.75	..	0.24	..	0.1	..	0.04	..
Aurophenine O ..	..	..	2.3	1.3	0.6	0.33	0.3	0.08
Thioflavine T ..	1.6	0.75	0.43	..	..	0.16	0.08	0.06

then, to the stage described above in which the intensity goes on increasing with dye concentration and all the concentrations lie below the optimum at which the intensity begins to decrease. It appears that Vavilov's theory (1943) is not applicable to this investigation as it is essentially based upon the migration of excitation energy due to quantum-mechanical resonance and our concentrations are not high enough for transfers of excitation energy to take place. The behaviour of the dye molecules as individuals is confirmed by the authors' finding that the values of the polarisation fit into the relation,

$$p = p_0/[1 + (1 - \frac{1}{3}P_0) RTkc/V\eta]$$

which is a modified form of Perrin's relation and includes a constant k and the concentration c of the dyestuff, the other symbols having the meaning given in section 3. The authors have found this relation to hold good for the range of concentrations used in their experiments. As a matter of interest, the values of k are given in Table 3. It may be noted that k increases with the molecular weight of the dyestuff and is probably a characteristic constant of the dyestuff.

TABLE 3.

Values of k ($\times 10^3$) and molecular weight.

	k	Molecular weight
Acridine Orange R ..	0.63	377
Safranine 6B ..	0.53	364
Thioflavine T ..	0.5	318
Aurophenine O ..	2.25	680

It may be of interest to mention here that Feofilov and Sveshnikov (1940) suggested the relation—

$$1/p = 1/p_0 + (1/p_0 - \frac{1}{3}) RT\tau/V\eta + Ac$$

where A is a constant and the other symbols have the same meaning as before. The authors, however, believe that the modified relation suggested by them is more suitable in that it has the advantage that it does not involve the mean lifetime of the excited states and hence knowing the viscosity, temperature and concentration and also the other constants, the degree of polarisation can be evaluated.

The decrease of the degree of polarisation and the increase of lifetime with concentration are now easy to explain. As each molecule has its own orientation,

the distribution of molecular orientations becomes more random with increasing concentration. As the absorption of incident energy by a molecule depends on its orientation with respect to the direction of vibration of the incident light, with increasing concentration, the emitted light becomes more isotropic resulting in a decrease in its polarisation. The increase of the mean lifetime with concentration is in accordance with the relation, $I_1/I_2 = \tau_1/\tau_2$, mentioned already in section 4(ii) as the intensity increases with concentration.

Above the optimum concentration, the intensity and mean lifetime can be expected to decrease as various decay processes may begin to operate (Frank and Livingston, 1949). It has been mentioned by Pringsheim (1949) that as the result of a decrease in the mean lifetime, the polarisation may begin to increase again. The main difficulty in extending the observations to higher concentrations is the low intensity of the fluorescent light.

These results considered along with those of Tawde and Ramanathan (1952), lead to the following conclusions. When the dyestuff is dissolved in a medium of high viscosity and the concentration of the dyestuff is low, the molecules of the dyestuff undergo practically no rotation within the lifetime of the excited states and the probability of loss of excitational energy by processes other than the emission of light is extremely small, the excited molecules spontaneously re-emitting light. At low viscosities and high concentrations of the dyestuff, the rotation of the molecules within the lifetime of the excited states as well as the probability of transfer of excitational energy to other non-excited molecules become appreciable and the chances of the excitational energy being given out spontaneously as fluorescent light are rare. At other conditions of the viscosity and concentration, in between the two extremes mentioned above, the predominance of rotation and transfer of energy depends on the exact conditions, the probabilities of these two processes varying from zero to unity. At very high concentrations, the intensity of the fluorescent light will be almost negligible while the lifetime of the excited states will also tend to zero because of the predominance of collisions and transfers of excitational energy to neighbouring molecules of the dyestuff. This is probably the reason why dyestuffs do not fluoresce when they are not sufficiently dispersed in some form of a solution.

ABSTRACT.

The effect of concentration of the dyestuff on the polarisation of fluorescence of dyestuff solutions, when excited by linearly polarised monochromatic light, is investigated. The results are discussed in the light of the recent theories of Vavilov and Förster and a modified form of Perrin's formula is suggested in order to include the factor of concentration of the dyestuff. A probable reason is given for the absence of fluorescence of dyestuffs when they are not sufficiently dispersed in the form of a solution.

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RAJPUTANA DESERT VEGETATION

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Very little work has been done on the desert vegetation of this country. Except a small area of Rajputana and a few spots here and there, there are very few places which may be considered desert in the true sense of the term. No floristic studies seemed to have been done properly even of these few desert and dry regions of India with deficient rainfall varying from 0" to 40" per year. Blatter, Hallberg and Sabnis studied plants of Jodhpur and Jaisalmer of the Rajputana desert and also of certain parts of Sind about thirty years ago. But very little scientific and authentic climatological and ecological data, influencing the xerophytic plant community of this part of India, have so far been recorded. It has been noticed of late that interest has been taken to trace the actual location of underground source of water in different dry zones of India. Some persons with empirical knowledge, following evidently some old traditional practices described in our ancient literature on the subject, gained some chance successes. These so-called miracle men are credited with supernatural powers as usual in this country by spiritually minded, and their services have even been requisitioned by the state for such purpose. It is gratifying that our National Institute intend to tackle the subject from proper scientific angle.

A glance over the different views, expressed during the discussion, however, seem to indicate that very little field work to solve the problem of arresting further encroachment of arable land by sandy waste and reclaiming the vast sandy and dry areas for the purpose of cultivation, has been attempted. Our discussion, as the President rightly hints, is more or less speculative and exploratory based on some scattered information. The need, therefore, for the study and proper scientific investigation of xerophytic flora and fauna in the sandy wastes of India, particularly from biological aspect of the question, will have to be undertaken anew on modern lines in a team work, keeping uniformity with similar investigation in other desert regions of the world as envisaged by UNESCO. The results of such a study of the desert vegetation of India and elsewhere will certainly throw some light on many a problem linked with human ecology and welfare.

Study of desert vegetation, so far India is concerned, should include xerophytic plants of the different types of successional order, mainly herbaceous and shrubby community as found to occur in various parts of our country. A thorough botanical, if not a joint biological survey of the country is therefore imperative to begin with, in order to locate the exact spots and actual areas covered by different types of the xerophytic (desert), the psamphytic (sand) and the halophytic (salt water) plant communities. These dry zones should be delineated accurately on the phytogeographical maps of India with a view to having at least one small station at each of the centres for recording correct meteorological, edaphic, geological, ecological, and other environmental factors which directly or indirectly influence the plant life occurring both as a simple unit or in a family, a society, a consociation, an association and finally a formation. But study of the life history of individual species occurring singly or in association with other species, that is autecology of plants, belonging to different genera, families, orders and classes growing within and under particular natural surroundings, is of greatest value in such an investigation.

Judged from the little information available at present, India may be divided into at least five more or less clear cut phytogeographical zones somewhat on the line adopted by Hooker years ago. Different species examined in the Herbarium and literature from each area indicate vast opportunities of collecting valuable information on various problems associated with the plant life in desert areas if proper field study is undertaken. There exist immense possibilities for the advancement of our knowledge on the subject both in its pure and applied aspects.

It is known that various meteorological and geological factors such as earthquake and upheaval of mountain ranges, change configuration of land masses. Various speakers made an attempt to view the question from different angles tracing back to Vedic period. No trace of any record of the floristic composition, however, of the desert areas of India, supposed to have been once fertile land, is available nor any authentic data of gradual conversion of the land once flowing with milk and honey, into dry and desolate sea of sand masses is traceable. It is doubtful how far these facts can be substantiated with scientific facts and figures.

The only feasible course is to proceed with the facts associated with the present-day flora and try to solve the problem in the light of the results obtained in recent times. The vegetation of the desert regions of the globe are dependent more or less on particular climatic and other factors, such as, rainfall, temperature, light, wind, relative humidity, physiography, habitat, edaphic, geological and last, but not least, the biotic factors.

The floristic study of the Indian deserts may better be understood against the background of the desert regions of the globe, most of which range near the tropic of Cancer and tropic of Capricorn.

The chief northern tropical deserts run from Southern California, Arizona, Mexico across the Sahara and round Arabia and then enter into the deserts of Persia, Afganistan, Beluchistan to the Sind and Thar desert in India. The vast central Asiatic desert lies in higher latitudes and it appears to be the North-Eastern branch of the African and the Arabian deserts and thus extends from the shores of the Caspian Sea to as far as Khingan mountains on the borders of Mongolia. The broken links of the Southern belt are found in the Atacama and Patagonia of S. America, Kalahari in S. Africa and the great Victoria desert and other smaller ones in Central Australia.

Vast bare expanses of flat or rolling plains covering wide areas of yellow sand dunes, broken and rugged rocky floor, ruined scraps of naked hills, sunbaked or windswept, sparingly dotted with low, dry, strange-looking plants or destitute of vegetation with its merciless, overwhelming light, temperature and awe-inspiring silence of its boundless wastes are a few of the manifold depressing aspects of the deserts. Deserts are caused by the absence of rain; but the cause of rainlessness may vary in the different regions from 0" to 40" per annum. A single shower in many years, excessively dry and clear atmosphere, cloudless skies, considerable and sudden changes of seasonal and diurnal temperature are the normal conditions of hot deserts. But the coastal deserts of the southern region, in Peru and Northern Chile and in S.W. Africa, are occasionally wrapped in mists.

The ground may be rocky, stony and gravelly, sandy or clayey. When rocky and clayey, it is covered with cracks and fissures produced by the abrupt alteration of temperature. The desert climate is also quite varied. Firstly, the coastal deserts of Peru and Chile and of S.W. Africa have alterations of burning days and cool nights when mists and dew may spread over the coasts. Secondly, the typical tropical deserts like the Sahara and those of Arabia, Rajputana and Central Australia have usually very hot days and extremely cold nights with cloudless skies. Thirdly, the deserts of high latitudes, found in Central Asia present greater extremes of temperature both daily and seasonal and also excessively cold winters.

Therefore, the vegetation of the desert varies according to the type of climate, availability of moisture and the nature of the subsoil present in the various desert

regions of the world. That is why the various deserts of the world, though they exhibit xerophytic vegetation characteristic of dry zones, present a remarkable variety in the component unit of the vegetation. Further, the habit, structure and life history of the desert plants are influenced to a great extent by the peculiar conditions present in the desert region. The plants in the desert have to depend on occasional showers at long intervals or on the subterranean water coming from surrounding area and from the residue of the scanty rain water which has sunk into the ground below the reach of evaporation. If the water level is so low to be out of reach, the plant becomes dormant, lives (often for years) in the shape of dust-like seeds. Those seeds which have survived the long sleep will, on the first showers of any consequence, burst into an intensely active life of very short duration. They sprout, grow, flower, fruit and seed, all within two or three weeks. The particular spot of the desert then becomes covered for a few days with a thin, bright carpet of ephemeral flowers, which disappear almost as quickly as they burst into bloom. But generally the structure of the various plants forming the desert vegetation shows great variations usually either in stem, root, or leaf characters adopting various methods like succulence, densely hairy, thorny, spiny, cuticular and waxy coatings, sunken stoma, tuberous or bulbous enlargement, deeply embedded and widely extended root system and various other adaptations, all to store as much water as possible and to protect themselves from the scorching heat and rapid evaporation in the desert regions.

To treat the subject against the above general background, the desert vegetation of India may be classified either according to rainfall, that is, the

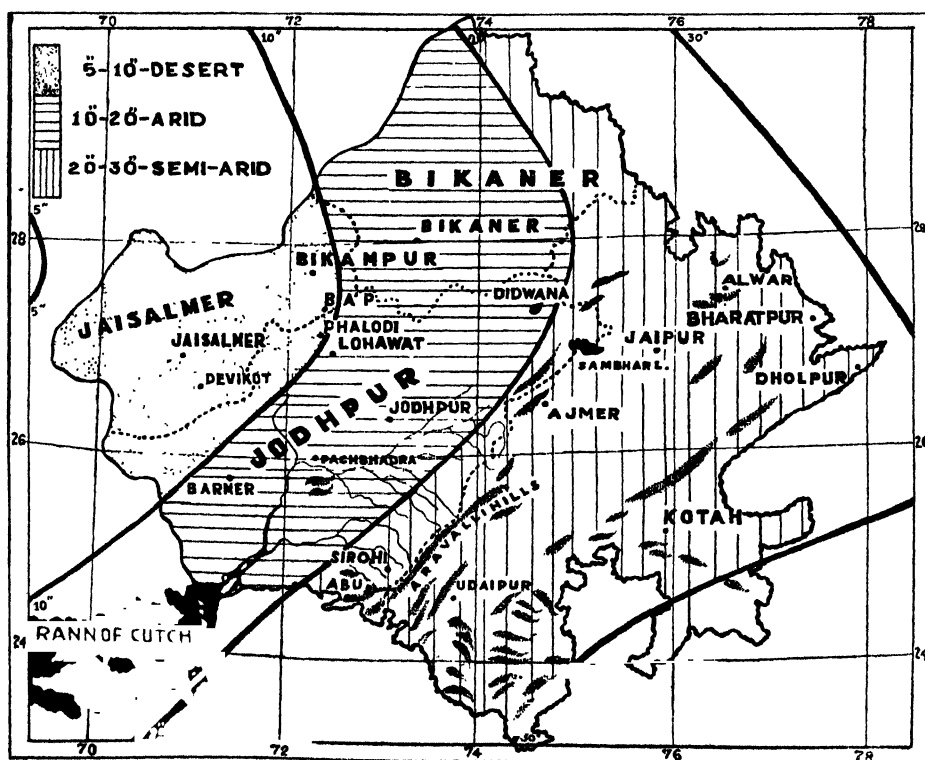


FIG. 1. Different Zones of Rajputana Desert in relation to Rainfall.

Scale 1" = 126 miles

species occurring in areas between 5" to 10", 10" to 20" and 20" to 30" precipitation per year (vide map) or on the basis of edaphic variations. Plant community in each of these areas, divided on the basis of rainfall, namely, the true desert, arid and semi-arid zones, seems to be rather small and less varied in composition of the species and number of species for obvious reasons. Therefore, the Rajputana desert vegetation should be studied specially with reference to edaphic variations in addition to the rainfall.

Taking into consideration the edaphic factors against the general poor rainfall, the Rajputana desert vegetation can be distinguished as (1) Sand Community (Psammophytes), (2) Gravel Community, and (3) Rock Community (Lithophytes). Each of these plant communities has been dealt with in the paper synecologically with casual reference to autoecology also.

Then again, the edaphic, climatic and other environmental factors result in consequential well-known xerophytic adaptations in different parts of the plants which have been casually noted under the respective units representing the different plant communities.

1. SAND COMMUNITY.

Sufficiently large portion of Western Rajputana is covered by blown sand chiefly consisting of powdered quartz grains with particles of calcium carbonate and fragments of local rocks. The presence of calcium carbonate particles seems to indicate that at least some of the sand in the desert has been carried by the wind from the distant limestone hills of Cutch. In fact, the whole sand mass is slowly moving in the direction of S.W.-N.E., being influenced by the strong South-West wind and also by North-East wind.

The formation of sand dunes of various shapes is mostly influenced by the action of the wind on the sand and also on the local configuration of the country, on the variation of strength and direction of the wind and in the supply of material. Sometimes the dunes are formed with extreme rapidity or at other times they may be bearly stationary as in a hollow between two hills. Particularly when the wind acts on the surface of the sand, sorting the various sand particles and thereby resulting in the formation of wind-ripples with the constant forward motion, germination of seeds is practically impossible and such areas are usually barren and completely devoid of vegetation.

The Psammophytic community includes some of the most characteristic associations of the region. Though it is very difficult for any plant to obtain a foothold on a rapidly shifting dune, sometimes hardy species such as, *Calotropis procera*, *Indigofera argentea*, *Crotalaria burhia*, *Leptadenia spartium*, *Aerva* and others are seen scattered over here and there. Of these *Calotropis procera* and *Indigofera argentea* are typical dune pioneers, perhaps best fitted to survive under such unfavourable habitat conditions with their rapidly growing thick, protruding, woody stems and strong, woody, deeply penetrating tap roots. On certain dunes near Phalodi, these plants form even somewhat pure consociation. In places where the sand spreads out over a large horizontal area, usually a consociation of *Aerva* consisting of two species, *A. tomentosa* and *A. pseudo-tomentosa* is formed. When an area is covered by the pioneers mentioned above, the most common plant of the region, namely, *Crotalaria burhia* quickly follows and overruns any portion of the sandy area which is not densely covered by the other pioneer vegetation. Along with this dominant member, *Crotalaria burhia*, other plants such as, *Leptadenia*, *Aerva*, *Panicum* form a characteristic consociation covering a very wide area of the sand dune near Loharki in Jaisalmer State. The bare inter-spaces formed in between the large tufts of the above-mentioned plants, are usually invaded by low growing species of *Convolvulus*, *Polygala* and others.

As regards the vegetation that prefers the very crest of the dune, *Calligonum polygonoideis* with its remarkable ability of adaptation to diverse circumstances, is

worth-mentioning. Starting from the crest and passing along the slopes, grasses like *Panicum turgidum* and *Pennisetum cenchroides* and other plants like *Indigofera*, *Crotalaria* and *Aerva* form a mixed association.

As regards the process of sand binding and arresting the advance of a dune more effectively, some of the stoloniferous members of Cyperaceae such as *Cyperus arenarius* appear to be more capable than other groups of plants, forming dense matty covering.

Besides the above plants, several other herbs belonging to the families Compositae, Malvaceae, Papilionaceae, Acanthaceae and Grammineae and shrubs like *Capparis*, *Grewia*, *Sericostoma*, *Euphorbia* and others and short stunted trees such as *Zizyphus*, *Salvadora*, *Prosopis*, *Acacia*, *Mimosa* and others form the components of the various consociations developing on the different sand dunes of the desert. Interestingly enough, a few species of fungi and Parasites like *Cuscuta hyalina*, *Cistanche tubulosa*, and *Cassytha filiformis* have been recorded from various host plants. Detailed list of the common desert plants is given in Appendix I. Some of the well-known xerophytic species of this desert mentioned above are shown in Plate XX.

2. GRAVEL COMMUNITY.

This plant community includes associations peculiar to the coarser type of sand or gravel covering large areas in the Rajputana desert. Due to the sorting action of wind by which the sand grains are being lifted and deposited on the dunes, the pebbles of the gravel are being left over presenting a dreary monotony of gravel plain. From the ecological point of view gravel area, though with firm surface layer, is unsuitable to support vegetation due to its very poor capacity to retain water with its large capillary cavities.

However, though the colonisation of a gravel area is a slow process, plants like *Boerhaavia diffusa* and *Cleome papillosa* form typical components of the community and are perhaps best adapted to such areas with long deeply penetrating tap-roots. Along with these, species of *Eleusine*, *Aristida*, *Fagonia* and others also develop in isolated patches. *Mollugo* species usually grow on fine gravel.

Other typical gravel plants forming dense mats with their branches to resist draught are *Corchorus antichorus*, *Seetzinia orientalis*, *Tribulus terrestris* and a few species of *Indigofera*.

Certain plants in gravel area develop bushy habit. Of those, *Sericostoma pauciflorum*, *Heliotropium* species, *Blepharis sindica*, *Anticharis linearis* are some of the prominent bushes in the Gravel Community.

Plants like *Laptadenia spartium* and *Calotropis procera* which are common in sand community, also develop quite common on gravel. Trees and shrubs such as, *Zizyphus rotundifolia*, often seen gregarious in certain places, *Prosopis*, *Salvadora*, *Gymnosporia*, *Capparis decidua* are common in the gravel formation. *Calligonum polygonoides* which is a shrub on sandy desert develops on gravel as a large climber with thick stem and pendulous branches. Species of *Eleusine*, *Pappophorum*, *Aristida* and sometimes *Perotis* prefer gravelly soil. The parasite, *Striga euphrasoides* mostly attack grasses growing on gravel.

3. ROCK COMMUNITY.

Apart from isolated hills and small rocky ridges, three important rocky areas in Jodhpur and Jaisalmer area may be mentioned, (1) The *Kailana-Jodhpur-Mandor plateau* covered extensively by sandstone of rather fine, gritty, reddish material. The plateau rises abruptly from the plain, attaining a height of about 200 ft., (2) *Jaisalmer plateau and outliers* composed of sandstone and also limestone preserving many fossils in their strata, (3) *Barmer hills*, chiefly of volcanic origin

consist of Malani rhyolites and reach a considerable height. These three areas present certain differences as regards the floristic composition of their associations with only very few species common to all the three areas.

The most characteristic rock plant or Lithophyte is *Euphorbia neriifolia* which is present in all the three areas forming dense shrubberies at various places supporting many climbers and twiners such as *Sarcostemma*, *Convolvulus*, *Capparis*, *Aerva*, *Pupalia* and many others. Other typical rock plants which favour invariably rocky substratum are *Barleria hochstetteri*, *B. acanthoides*, *Ruellia patula* var. *alba*, *Farsetia macrantha* of Cruciferae, the rare family of this desert region, *Lepidagathis trinervis*, *Indigofera cordifolia*, *Tephrosia petrosa*, *Orygia decumbens* (Ficoideae), *Pegolettia senegalensis* (Compositae), *Bouchea marrubifolia* (Verbenaceae) and grasses like *Gracilea royleana*, *Elionurus*, *Aristida*, and others. It may be mentioned, however, that the members of Cyperaceae are almost entirely absent from the rocky area.

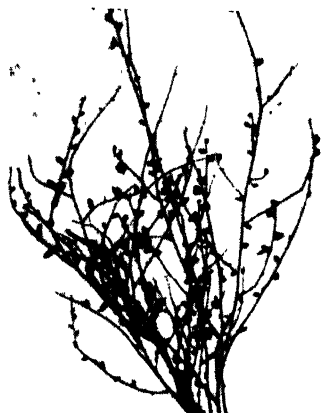
Usually after heavy rains small patches of Crustaceous Lichens on the stones and gelatinous brown lumps of blue green algae (members of *Aphenocapsa* ?) among the grasses appear. *Actinopteris dichotoma*, a member of the Filicales has also been reported from Barmer hills.

Apart from these, there is often found an ephemeral community, the members of which represent a rather heterogenous assemblage completing their life-cycle within a short space of time. Several weeds of cultivated fields, Ruderals and escapes owe their presence in one way or other in the immediate surroundings of villages due to certain changes brought about by Biotic factor. They are species of *Mollugo*, *Trianthema*, *Digera*, *Amaranthus*, *Solanum*, *Datura*, *Alysicarpus*, *Tephrosia*, *Sesbania*, *Tridax*, *Boerhaavia* and *Eragrostis*. These have seeds which are zoochorous and anemochorous. One of the most remarkable plants in sandy soil of this region, originally cultivated but now completely established requiring no care whatsoever, is *Citrullus vulgaris*, the common water melon. Other members of cucurbitaceae and also *Sesamum indicum* and *Tamarix orientalis* appear to be establishing themselves.

It is observed very many migratory and floating mesophytic species also occur here and there during the moist season. Some Indian aquatic and amphibious plants such as, *Nymphaea*, *Bergia*, *Ammania*, *Trapa*, *Ipomaea aquatica*, *Potamogeton*, *Naias*, *Cyperus* and others are also found to occur in and along the sides of the ridges of temporary pools and puddles formed during the rains. All these live an ephemeral life and are not certainly xerophytic plants. These species, however, have been noted separately in the systematic enumeration of species showing their transient existence in this area.

Of the arboreal vegetation, the trees found to grow here and there in the desert are mostly stunted, gnarled and of various fantastic shapes. These are very few in number and do not form any particular association of their own for obvious reasons. Mention has, however, been made in the systematic enumeration of the different species of trees growing in these desert areas.

It may be mentioned that the general vegetation of the Rajputana desert consists of about 70 families with about 300 genera and 550 species representing the desert flora. Of these, nearly 58 families with 220 genera and 440 species have been considered as indigenous. Of the various families, the first five dominant families are Gramineae, Leguminosae, Compositae, Cyperaceae and Convolvulaceae. Monocotyledons are comparatively poorly represented forming less than one-third of the Dicotyledonous species. In general, three distinct elements, namely, a Western, an Eastern and a more general element (including purely Indian species also) can be distinguished in the flora of the Rajputana desert. Of the three elements, the Western with nearly 200 species and the Eastern (Indo-Malayan) with nearly 30 species, may be considered from phytogeographical point of view in dealing with the composition of the Rajputana desert flora. So the basic element



Top (1) *Crotolaria burhia* Ham.
Middle (2) *Calligonum polygonoides* L.
Bottom (3) *Cyperus arcuatus* Roxb.

(4) *Calligonum polygonoides* L.
(5) *Cyperus arcuatus* Roxb.
(6) *Calotropis procera* Br.

is about one-seventh of the Western and thereby indicating that the Indo-Malayan and the Western botanical regions meet in the Western Rajputana desert with the preponderance of the Western element. Hence the line of demarcation between the Indo-Malayan flora and the Perso-Arabian flora, ranging from the gulf of Cambay northwards along the Aravallis as suggested by Drude, appears to be correct.

SUMMARY.

Rajputana desert has been dealt with against the background of the deserts of the world and divided into three zones, namely, the true desert zone, the arid zone and the semi-arid zone on the basis of rainfall as illustrated in the map. The vegetation has also been treated under three different plant communities, namely, the Sand, the Gravel and the Rock communities with reference to the edaphic and other environmental factors. The nature of the various species forming characteristic consociations and associations in the three communities occurring in Jodhpur and Jaisalmer States has been discussed. Notes on plants comprising the ephemeral community growing in and adjacent to temporary ponds and pools, cultivated areas and arable land have briefly been incorporated.

The genera and species composing the Rajputana desert indicate that the demarcating line between the Indo-Malayan and the Perso-Arabian floras appears to run from the Gulf of Cambay northwards along the Aravallis. A systematic enumeration of the species of those parts of the Indian desert which are represented in the Calcutta Herbarium and also available in the literature has been added.

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Systematic Enumeration of the Rajputana Desert Plants.

I. HERBS.

- Cocculus cebatha* DC. } .. Menispermaceae.
C. hirsutus Diels }
Argemone mexicana L. .. Papaveraceae.
Farselia jacquemontii Hook. f. & T. .. Cruciferae.
Cleome papillosa Steud.
C. brachycarpa Vahl } .. Capparidaceae.
Gynandropsis pentaphylla DC.
Cadaba indica Lam.
Capparis spinosa L.
Viola stocksii Boiss. .. Violaceae.
Polygala erioptera DC. } .. Polygalaceae.
P. irregularis Boiss.
Polycarpacea corymbosa Lam. .. Caryophyllaceae.
Portulaca oleracea L. } .. Portulacaceae.
P. quadrifida L.
Sida spinosa L.
S. greuioides Guill.
S. cordifolia L.
Abutilon indicum Sw.
A. glaucum Cav.
A. bidentatum A. Rich.
A. fruticosum Guill.
A. cornutum T. Cooke
Pavonia arabica Steud.
P. zeylanica Cav.
P. odorata Willd.
Hibiscus micranthus L.
Abelmoschus moschatus Modik. } .. Malvaceae.
Corchorus trilocularis L.
C. depressus (L.) Chr. } .. Tiliaceae.
C. tridens L.
Tribulus terrestris L.
T. alatus L.
Seetzenia orientalis Dene. } .. Zygophyllaceae.
Zygophyllum simplex L.
Peganum harmala L.
Mansonia senegalensis Guill. & Perr. } .. Geraniaceae.
M. heliotropioides Boiss.
Erodium cicutarium L' Herit ex Ait.
Cardiospermum halicacabum L. .. Sapinduceae.
Heylandia latebrosa DC.
Orotalaria burhia Ham.
C. medicaginea Lam.
Indigofera linifolia Retz.
I. cordifolia Heyne
I. oblongifolia Forsk.
I. argentea (non Linn.) Burm.
I. articulata Gouan
I. anabaptista Steud. } .. Papilionaceae.
Tephrosia multiflora Blatt. & Hall.
T. hirta Ham.
Psoralea odorata Blatt. & Hall.
Alysicarpus vaginalis DC.
Phaseolus trilobus Ait.
Rhynchosia arenaria Blatt. & Hall.
R. rhombifolia Blatt. & Hall.
Alhagi camelorum Fisch.
Neurada procumbens L. .. Rosaceae.
Vahlia viscosa Roxb. .. Saxifragaceae.
Momordica dioica Roxb.
M. balsamina L.
Cucumis melo L. } .. Cucurbitaceae.
Citrullus colocynthis Schrad.
Melothria maderaspatana Cogn. }

- Trianthema triquetra* Rottl. & Willd. }
T. pentandra L. }
Orygia decumbens Forsk. } .. Ficoideae.
Mollugo lotoides Ktze.
M. nudicaulis Lam.
M. cerviana Ser.
Gisekia pharnaceoides L.
Limeum indicum Stocks
Borreria stricta (L.) Sch. } .. Rubiaceae.
B. hispida (L.) Sch.
Vernonia cinerascens Schult. }
Pegolettia senegalensis Cass. } .. Compositae.
Pulicaria angustifolia DC.
P. rajputanae Blatt. & Hall.
Echinops echinatus R.
Volularella divaricata Bth.
Dicoma tomentosa Cass.
Launea chondrilloides H.f.
Glossonema varians Benth. } .. Asclepiadeae.
Pentstemon cynanchoides Br.
Periploca aphylla Dcne.
Enicostemma littorale Bl. .. Gentianaceae.
Heliotropium supinum L.
H. rariflorum Stks. } .. Boraginaceae.
H. undulatum Vahl
H. zeylanicum Lamk.
Trichodesma indicum Br.
Arnebia hispidissima DC.
Cressa cretica L.
Breweria latifolia Bth.
Convolvulus microphyllus Seit. } .. Convolvulaceae.
C. glomeratus Choisy
Ipomea indica Stapf
I. hispida R. & S.
I. pestigridens L.
Solanum xanthocarpum Schrad. & Wendl. } .. Solanaceae.
S. incanum L.
S. albicaule Kotschy ex Dunal
Withania somnifera Dunal
Anticharis linearis Hochst. } .. Scrophulariaceae.
Schweinfurthia sphaerocarpa Braun.
Blepharis indica T. Anders.
Dipteracanthus patulus (Jacq.) Nees } .. Acanthaceae.
Barleria hochstetteri Nees
Justicia simplex D. Don
Lepidagathis trinervis Nees
Peristrophe bicalyculata Nees
Bouchea marrubifolia Schauer .. Verbenaceae.
Leucas aspera Spreng. .. Labiatae.
Boerhaavia diffusa L. } .. Nyctaginaceae.
B. verticillata Poir.
B. elegans Choisy.
Aerva tomentosa Forsk.
A. pseudo-tomentosa Blatt. & Hall. } .. Amaranthaceae.
Achyranthes aspera L.
Pupalia lappacea (L.) Juss.
Polygonum plebejum Br. .. Polygonaceae.
Aristolochia bracteata Retz. .. Aristolochiaceae.
Euphorbia granulata Forsk. } .. Euphorbiaceae.
E. microphylla Heyne
Phyllanthus niruri L.
Asparagus racemosus Willd. } .. Liliaceae.
Dipcadi erythraeum Webb. & Benth.
Commelina albescens Haask. .. Commelinaceae.
Cyperus niveus Retz.
C. arenarius Retz. } .. Cyperaceae.
C. rotundifolius Rottb.
Fimbristylis tenera R. & S.

IV. AQUATIC AND SEMI-AQUATIC PLANTS IN THE DESERT LAKES AND PONDS.

- Chara* .. Characeae (Algae).
Nymphaea lotus L. ... Nymphaeaceae.
Bergia ammannioides Roxb. } .. Elatinaceae.
B. odorata Edgew. }
Ammannia baccifera L. } .. Lythraceae.
A. desertorum Blatt. & Hall. }
Trapa bispinosa Roxb. (Cultd.) .. Onagraceae.
Eclipta erecta L. .. Compositae.
Ipomoea reptans Poir .. Convolvulaceae.
Potamogeton pectinatus L. } .. Potamogetanaceae.
P. crispus Linn. }
Najas graminea Del. } .. Najadaceae.
N. australis Bory ex. Cham. }
N. welwitschii Rendle }
Cyperus pygmaeus Rottb. }
C. aristatus Rottb. } .. Cyperaceae.
C. iria L. }
C. bulbosus Vahl }
C. rotundus L. }
Fimbristylis tenera Roem. & Schult. }
Scirpus quinquefarius Ham. }
S. maritimus L. }
Paspalidium geminatum Stapf } .. Gramineae.
Sporobolus glaucifolius Hochst. }
Desmostachya bipinnata Stapf }
Eragrostis pilosa Beauv. }
E. interrupta Beauv. }

V. PARASITES.

- Cuscuta hyalina* Roth. }
 (Parasitic on Ficoideae, Tribulus, Calotropis procera, Aerva, } .. Convolvulaceae.
Amaranthus polygamus, Boerhaavia, Desmodium, Rhynchosia) }
Striga orobanchoides Benth. } .. Scrophulariaceae.
S. euphrasioides Benth. }
Cistanche tubulosa Wt. }
 (On Capparis decidua) .. Orobanchaceae.
Cassytha filiformis L. .. Lauraceae.

VI. PLANTS OF SEMI-DESERT REGION. (EASTERN RAJPUTANA AND SURROUNDINGS.)

- Salmaalina malabarica* Schott. & Endl.
Sterculia urens Roxb.
Semecarpus anacardium Linn. f.
Anogeissus latifolia Wall.
A. pendula Edgew.
Gmelina arborea L.
Erythrina suberosa Roxb.
Bauhinia purpurea Linn.

Apart from the above trees there are many plants of the desert occurring in this region also. The Aravali Hill tracts present considerably dense vegetation compared to the desert tract of the Western Rajputana and Mt. Abu with its high altitude, favours the development of some of the Himalayan plants like *Aerides*, *Rosa*, *Girardinia*, *Michelia* and others. This area needs careful survey and is likely to yield fruitful results.

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DEGENERATE GAS AND THE MOTION OF A PARTICLE IN A HARMONIC FIELD

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The density distribution of a degenerate Fermi-Dirac gas in a uniform field of force has been discussed by Kothari and Auluck (1942). In the present paper we consider a similar problem where the field of force is not uniform but its gradient is constant. The density distribution is first obtained with the help of Gibbs free energy for degenerate gas. In section 2, it is obtained directly by solving the wave equation for a particle moving in a constant-gradient field and subject to proper boundary conditions. The generalization of the result to more than one dimension is discussed in the last section.

1. Consider an assembly of Fermi-Dirac particles in field-free region of volume V and at temperature T . The Gibbs free energy per particle is given by

$$G = kT \log A, \quad \dots \dots \dots (1)$$

A being the degeneracy parameter.

For the (non-relativistic) completely degenerate gas, we have

$$G = \frac{h^2}{2m} \left[\frac{3n}{4\pi g} \right]^{\frac{2}{3}} \dots \dots \dots (2)$$

Let us now consider the gas placed in a field of force directed along the x -axis. The density distribution for the gas will be given by

$$G(x_1) - G(x_2) = W(x_1, x_2) \quad \dots \dots \dots (3)$$

where $W(x_1, x_2)$ is the work done against the field in carrying a particle from x_1 to x_2 and $G(x_1)$ and $G(x_2)$ are the values of Gibbs energy at these two points.

From (2) and (3) we have

$$\frac{h^2}{2m} \left[\frac{3n_0}{4\pi g} \right]^{\frac{2}{3}} - \frac{h^2}{2m} \left[\frac{3n}{4\pi g} \right]^{\frac{2}{3}} = \frac{1}{2} \alpha x^2. \quad \dots \dots \dots (4)$$

Since n vanishes for $x > l$, equation (4) becomes

$$n = \frac{4\pi g}{3} \left(\frac{m\alpha}{h^2} \right)^{\frac{3}{2}} (l^2 - x^2)^{\frac{3}{2}}, \dots \dots \dots (5)$$

where l is given by

$$l = \left(\frac{h^2}{m\alpha} \right)^{\frac{1}{2}} \left[\frac{3n_0}{4\pi g} \right]^{\frac{1}{3}} \dots \dots \dots (6)$$

The total number of particles contained in a cylinder of unit cross-section will be

$$\bar{n} = \int_0^{\infty} n dx = \frac{\pi^2 g}{4} \left(\frac{m\alpha}{h^2} \right)^{\frac{3}{2}} l^4. \quad \dots \dots \dots (7)$$

We shall now obtain the same result from wave-mechanical considerations. Consider the particle enclosed in a box which is bounded by the planes $x = 0$, $y = 0$, $y = l_2$, $z = 0$ and $z = l_3$. The wave equation for the particle is

$$\Delta\psi + \frac{8\pi^2 m}{h^2} (E - \frac{1}{2}\alpha x^2)\psi = 0 \quad \dots \dots \dots (8)$$

and hence we have

$$\psi = A \sin \frac{\pi n_2}{l_2} y \sin \frac{\pi n_3}{l_3} z X(x), \quad \dots \dots \dots (9)$$

where $X(x)$ satisfies the equation

$$\frac{d^2 X}{dx^2} + \frac{8\pi^2 m}{h^2} (E - \frac{1}{2}\alpha x^2)X = 0. \quad \dots \dots \dots (10)$$

The solution of this equation is

$$X(x) = c e^{\frac{-kx^2}{2}} H_n(\sqrt{k}x), \quad \dots \dots \dots (11)$$

where H_n 's denote the Hermite polynomials of odd orders, and λ is restricted by the relation

$$\lambda = (4n_1 + 3)k, \quad \dots \dots \dots (12)$$

n_1 being equal to 0, 1, 2, 3,

where

$$\lambda = \frac{8\pi^2 m}{h^2} \left[E - \frac{h^2}{8m} \left(\frac{n_2^2}{l_2^2} + \frac{n_3^2}{l_3^2} \right) \right] \quad \dots \dots \dots (13a)$$

and

$$k^2 = \frac{4\pi^2 m\alpha}{h^2}. \quad \dots \dots \dots (13b)$$

From (12) and (13a), we have

$$-\frac{8mE}{h^2} - \frac{3k}{\pi^2} = -\frac{n_1}{\pi^2} + \frac{n_2^2}{l_2^2} + \frac{n_3^2}{l_3^2}.$$

Writing γ for $\frac{\pi^2}{4k}$ and β^2 for $-\frac{8mE}{h^2} - \frac{3k}{\pi^2}$ we have

$$\frac{n_1}{\gamma} + \frac{n_2^2}{l_2^2} + \frac{n_3^2}{l_3^2} = \beta^2. \quad \dots \dots \dots (14)$$

We shall now calculate the number of eigenfunctions, which for energies $\leq E$, is the volume of the space bounded by the three co-ordinate planes and the surface described by (14). The number of eigenfunctions will be g times the above value,

if weight factor is to be included. The area of the positive quadrant of the elliptic section, if we assume n_2 and n_3 to be varying and n_1 to be fixed, will be,

$$\frac{\pi}{4} l_2 l_3 \left(\beta^2 - \frac{n_1}{\gamma} \right). \quad \dots \quad (15)$$

Hence the required volume is

$$V = \frac{\pi}{8} l_2 l_3 \gamma \beta^4. \quad \dots \quad (16)$$

Now for the completely degenerate gas, the number of particles is equal to the number of independent wave functions, so we have,

$$\bar{n} = g \frac{\pi}{8} \gamma \beta^4 \quad \dots \quad (17a)$$

or

$$= \frac{\pi^2 g}{32} \left(\frac{h^2}{4m\alpha} \right)^{\frac{1}{2}} \left[\frac{8mE}{h^2} - 6 \left(\frac{m\alpha}{\pi^2 h^2} \right)^{\frac{1}{2}} \right]^2 \quad \dots \quad (17b)$$

This expression gives us the density distribution of completely degenerate gas in a field of force whose gradient is constant. The second term within the parenthesis arises due to the fact that the particles possess null-point energy. The second term, being very small compared to the first term, can be ignored. So we have from above,

$$\bar{n} = \frac{\pi^2 g}{4} \left(\frac{m\alpha}{h^2} \right)^{\frac{3}{2}} l^4 \quad \dots \quad (18)$$

3. In the preceding section, we have discussed the case when the field is only along the x -direction. We shall now consider the field to be along x and y -axes. The Schrödinger equation

$$\Delta\psi + \frac{8\pi^2 m}{h^2} (E - \frac{1}{2}\alpha_1 x^2 - \frac{1}{2}\alpha_2 y^2) \psi = 0 \quad \dots \quad (19)$$

has the solution

$$\psi = A \sin \frac{\pi n_3}{l_3} z X(x) Y(y), \quad \dots \quad (19a)$$

where $X(x)$ and $Y(y)$ satisfy the relations,

$$\frac{d^2 X}{dx^2} + \frac{8\pi^2 m}{h^2} (E_x - \frac{1}{2}\alpha_1 x^2) X = 0, \quad \dots \quad (20a)$$

and

$$\frac{d^2 Y}{dy^2} + \frac{8\pi^2 m}{h^2} (E_y - \frac{1}{2}\alpha_2 y^2) Y = 0. \quad \dots \quad (20b)$$

The total energy E is given by the relation,

$$E = E_x + E_y + \frac{h^2}{8m} \frac{n_3^2}{l_3^2}. \quad \dots \quad (20c)$$

The solutions of (20a) and (20b) will be analogous to (11), and the eigenvalues are given by

$$k_1 = (4n_1 + 3) k_1, \quad \dots \quad (21a)$$

$$k_2 = (4n_2 + 3) k_2, \quad \dots \quad (21b)$$

where n_1 and n_2 are positive integers and λ_1, k_1^2 stand for $\frac{8\pi^2 m E_x}{h^2}$ and $\frac{4\pi^2 m \alpha_1}{h^2}$ respectively. Similar expressions hold for λ_2 and k_2^2 .

From (20c), (21a) and (21b) we have,

$$\frac{n_1}{\gamma_1} + \frac{n_2}{\gamma_2} + \frac{n_3^2}{l_3^2} = \beta^2. \quad \dots \quad (22)$$

$$\beta^2 \text{ now stands for } \left[\frac{8mE}{h^2} - \frac{3k_1}{\pi^2} - \frac{3k_2}{\pi^2} \right]$$

$$\text{and } \gamma_1, \gamma_2 \text{ for } \frac{\pi^2}{4k_1} \text{ and } \frac{\pi^2}{4k_2} \text{ respectively.}$$

In this case the volume of the space will be,

$$V = \frac{4}{15} \gamma_1 \gamma_2 l_3 \beta^5. \quad \dots \quad (23)$$

Therefore, the density distribution will be

$$\bar{n} = g \frac{\pi^2 h^2}{60m} \left(\frac{1}{16\alpha_1 \alpha_2} \right)^{\frac{1}{2}} \left[\frac{8mE}{h^2} - 6 \left(\frac{m\alpha_1}{h^2} \right)^{\frac{1}{2}} - 6 \left(\frac{m\alpha_2}{h^2} \right)^{\frac{1}{2}} \right]^{\frac{5}{2}}. \quad \dots \quad (24)$$

The above treatment can be generalized to hold for any number of dimensions. In v -dimensions (14) becomes

$$\frac{n_1}{\gamma} + \sum_{i=2}^v \frac{n_i^2}{l_i^2} = \beta^2, \quad \dots \quad (25)$$

and (15) will be replaced by

$$\frac{\pi^{\frac{v-1}{2}}}{2^{v-1} \Gamma\left(\frac{v+1}{2}\right)} \left(\beta^2 - \frac{n_1}{\gamma} \right)^{\frac{v-1}{2}} \prod_{i=2}^v l_i. \quad \dots \quad (26)$$

Finally, the density distribution for the v -dimensional case will be

$$\bar{n}_v = g \frac{\pi^{\frac{v-1}{2}} \gamma}{2^{v-1} \Gamma\left(\frac{v+1}{2}\right)} \cdot \left(\frac{2}{v+1} \right) (\beta^2)^{\frac{v+1}{2}}. \quad \dots \quad (27)$$

The corresponding Bose-Einstein case with possible applications to He II will be discussed in another paper.

Our thanks are due to Prof. D. S. Kothari and Dr. F. C. Auluck for suggesting the problem and helpful discussion.

ABSTRACT.

The density distribution of Fermi-Dirac degenerate gas in a field of constant gradient is considered. The results are obtained using Gibbs free energy and also by solving the wave equation.

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Kothari, D. S. and Auluck, F. C. (1942) Degenerate gas and the Motion of a particle in a uniform field. *Proc. Nat. Inst. Sci. India*, 8, 157.

THE FOOD AND FEEDING HABITS OF THE BOMBAY DUCK, *HARPODON NEHEREUS* (HAM.) IN THE RIVER MATLAH (BENGAL)

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INTRODUCTION.

The Bombay duck, *Harpodon nehereus* (Ham.), is one of the important food fishes of Indian waters, and according to the Handbook of Indian Fisheries (1951), the total catch for 1949-50 was about 7,250 tons, forming about 2% of the total marine fish landed in India. Though well relished and considered a delicacy in Western India, its culinary qualities have not been recognised in West Bengal. In this State, sizeable quantities are landed during the fishing season on the Midnapore Coast and almost throughout the year in the estuarine areas, but it is usually eaten only by the poorer classes, and the price of the fish is relatively low, not being more than 4-6 annas a pound.

Hora (1934) described in brief its fishery in Indian waters and pointed out the paucity of information regarding its biology. He suggested that it will be of great interest if detailed investigations are carried out to elucidate its bionomics. Hora examined two samples of the stomach contents of the fish, supplied by Dr. S. B. Setna from Bombay waters and found that *Bregmaceros maclellandi* Thompson and *Acetes indicus* Milne Edwards formed its principal food. Based on this and the co-extensive nature of the distribution of the Bombay duck and these food species, he suggested that the wanderings of the Bombay duck are probably influenced by the wanderings of the food species. He recommended a closer investigation of the problem. Chopra (1939) remarked that the Bombay duck feeds largely on shrimps and its migration can generally be traced by the movements of the shoals of shrimps. According to Mookerjee, Ganguly and Mazumdar (1946) the food of the Bombay duck consists of unicellular algae 2%; Protozoa 8%, Worms 6%, Crustacea 44%, appendages of Crustacea 10%, and fish 30%. In the Handbook of Indian Fisheries (1951), it is mentioned as a carnivore feeding mainly on prawns.

Excepting these, there are no detailed records of the food and feeding habits of this fish.*

The present study was undertaken with two objects in view. One was to throw further light on the food and feeding habits of the fish and facilitate a better understanding of its migrations as suggested by Hora. The other and more immediate object was to determine its status as a predator of Grey Mulletts in connection with my studies on their biology. The investigation was considered of special interest, in view of its alleged highly piscivorous habits. A preliminary note on the subject was published recently (1951a), and the present paper is a detailed discussion of the findings.

MATERIAL AND METHODS.

The material utilised for this study was collected from Port Canning on the River Matlah (24-Parganas—W. Bengal). Matlah is a tidal river, and according to Kemp (1917) the depth of the river varies from $4\frac{1}{2}$ –8 fathoms, the maximum height of tide being about 10–15 feet. The water is heavily laden with silt and the salinity of the water varies greatly during different seasons. The river bottom is composed of very finely divided soft mud and due to swift running currents the upper layers of mud on the river bed are always kept in motion and partial suspension. Samples were obtained for a period of ten months from March to December. Attempts were made to obtain samples in January and February, but they were not available during the times of visit. One thousand and forty-eight specimens ranging from 38 mm.–265 mm. in total length have been examined in detail. They were obtained from the fishermen, who had caught them in the *Behundi jal*, a fixed bag net (Naidu, 1942), during the high and low tide periods.

The specimens were fixed in 5% formaldehyde and brought to the laboratory for detailed examination. In the laboratory, the total length of each fish, the condition of its gonads and condition of feed were noted. The condition of feed was determined by the degree of distension of the stomach (Job, 1940 and Pillay, 1951), and classified as 'Gorged', 'Full', 'Half full', ' $\frac{1}{4}$ full', 'With little food', 'With very little food' and 'Empty'. The gut was then dissected and the contents removed into a petri dish for qualitative and quantitative analyses. Very often the food matter in the gut, especially the crustacean matter was found to be in an advanced state of digestion and so in many cases, only the generic identification of the food components was possible. The quantitative analysis was done by the volumetric method, in which the volume of each food item is expressed as a percentage of the volume of the total gut contents (Hynes, 1950). Since the fish was found to be carnivorous in habits it was possible to assess the volume by the displacement method. The gut contents were sorted out and the total volume of each item of food was determined by the displacement method in a measuring cylinder graduated to 0.1 c.c., and its percentage calculated. The prevalence of each item of food in the diet during different months was calculated by the occurrence method (Hynes, *op. cit.*). In this method the number of fish in which each food item occurs is expressed as a percentage of the total number of fish examined. The possibility of the fish devouring its own young or other fishes fortuitously, while in the net

* After this paper was prepared, a contribution entitled 'Observations on the biology of *Harpodon nehereus* (Hamilton), by S. V. Bapat, S. K. Banerji and D. V. Bal (*J. Zool. Soc. India*, 3, pp. 341–356) containing more detailed information on the food habits of the fish in Bombay waters has appeared. These workers have found that prawns form the main food of the fish, the other important items being *Harpodon nehereus* itself, *Bregmaceros maclellandi*, *Coilia dussumieri* and *Eleutheronema tetradactylum* and that the disappearance of the usual food, probably causes the disappearance of the fish from the local waters. Their observations are very much in agreement with the findings of Hora (1934). From the data discussed in the present paper it will be found that there are some very marked differences in the food and feeding habits of this fish in the estuarine waters of the Matlah River.

before they are hauled up, or even after that before they die, has been kept in mind in analysing the gut contents. From detailed individual records, monthly averages were calculated and from this the total percentage composition by volume or occurrence were determined. The data for young ones were analysed separately; but since no significant difference, except in the size of the food species consumed was observed, the food of young ones have not been considered separately in this paper.

FOOD HABITS.

State of Feed.

The state of feed of 1048 specimens examined during the investigation is presented in Table I. From this it will be evident that there is no marked season of intensive feeding discernible, and in all months except August, a good percentage of the guts examined was in a gorged or full state of feed. In August, however, 28% of the fish examined had only little food in their guts and 36% of them were completely empty. This is due to the abundance of young ones during the period and the fact that a good percentage of the sample for the month consisted of these. Most of the young ones had their guts empty. The Bombay duck is believed to spawn in the sea and the young ones ascend the estuary for feeding. The fish caught in the bag net during high tides are mainly those that come up the estuary with the tide. There is some probability that the migrating young ones do not feed. However, this needs further intensive observations to establish. A few maturing specimens were examined in the months of May and June, and their guts were completely empty.

TABLE I.

The State of Feed of Bombay duck examined from Mullah River.

Month.	Gorged.	Full.	$\frac{3}{4}$ full.	$\frac{1}{2}$ full.	$\frac{1}{4}$ full.	Little.	Very little.	Empty.
March ..	6.0	14.0	10.0	12.0	8.0	12.0	2.0	36.0
April ..	28.3	31.7	1.7	6.7	3.3	3.3	..	25.0
May ..	29.5	21.6	4.5	6.8	6.8	4.5	1.3	25.0
June ..	16.0	42.0	2.0	4.0	2.0	14.0	..	20.0
July ..	8.0	48.0	8.0	8.0	4.0	4.0	2.0	18.0
August ..	16.0	..	..	12.0	8.0	28.0	..	36.0
September ..	13.7	26.3	5.3	10.5	8.4	9.5	2.1	24.2
October ..	4.0	34.0	2.0	10.0	..	16.0	..	34.0
November ..	10.0	52.0	2.0	14.0	4.0	12.0	..	6.0
December ..	5.0	40.0	..	10.0	15.0	5.0	..	25.0

Analysis of Gut Contents.

The average volumetric composition of the food of the fish as judged by the analysis of gut contents is represented in the Pie diagram (Fig. 1). From this it can be seen that prawns and shrimps formed the most predominant food of the fish. 60.3% of the bulk of its food consisted of this item and 66% of the fish examined had consumed them. The young ones of the same species (Bombay duck) formed 17.5% of the total gut contents which shows the marked cannibalistic habits of the fish. 19.6% of the guts had this item. Other fishes together formed the next item of importance as an article of diet and constituted 10.9% of the total gut contents. This had been eaten by 12.4% of the specimens examined. *Megalopa* larvae formed 7.1% of the bulk of the gut contents, and occurred in 10.3% of the guts examined.

Other items that were consumed by the fish were plant matter and detritus. About 1.9% and 2.3% of the gut contents consisted of these items respectively, and 2.9% and 4% respectively of the specimens examined had them in the guts.

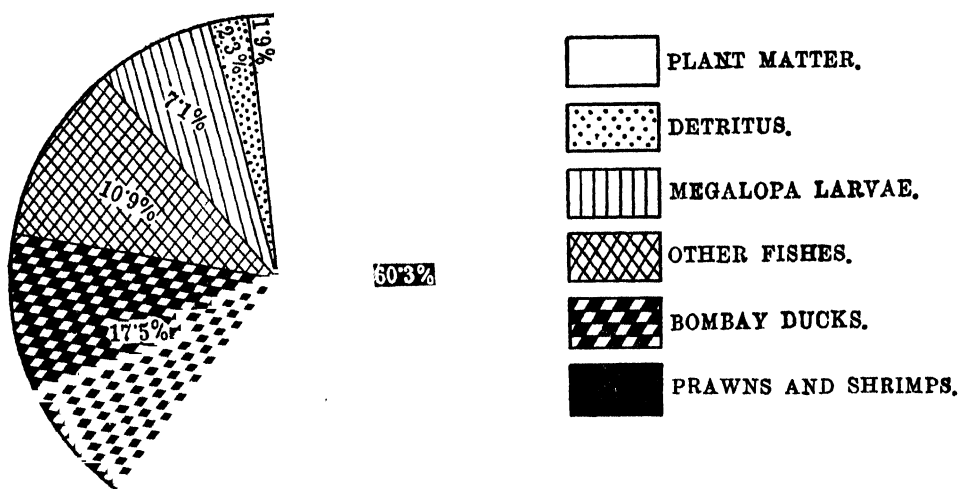


FIG. 1. The pie diagram showing the volumetric composition of the food of the Bombay duck.

Food components and the fluctuations in their occurrence in the gut contents.

Prawns and Shrimps.—Both young and adult prawns and shrimps were found in the gut contents. The specific identification of these proved very difficult because of the fact that most of them had been acted upon by the digestive juices in the stomach. Sergestids, chiefly *Acetes* spp., were found to be the most predominant group, the next in importance being Penaeids. *Leander styliferus* Milne Edwards formed a very common item in the gut contents.

The monthly fluctuations in the quantity of the items in the gut contents and the forms that constituted them are presented in Table II and Fig. 2. The prevalence of these items during different months is given in Table III. It can be seen from these that considerable quantities of prawns and shrimps were eaten throughout the period of investigation. March, July and October-December were peak periods in their occurrence, both in quantity eaten and in their prevalence in the diet. In April, May and August, the quantities consumed were relatively low.

Bombay ducks.—The young of Bombay duck appeared as an important item in the gut contents. Though mostly young ones were eaten, even larger specimens, as long as 9 cm., have been observed. A specimen 17.5 cm. long, examined in the month of June, had a 9 cm. long semi-digested Bombay duck in its stomach. The smallest cannibalistic specimen observed was 6.6 cm. long, examined in June, which had eaten an young one of about 2.5 cm. length.

Reference to Table II, and Fig. 2, will show evidence of cannibalism in the fish during all the months of investigation, except March. But generally this cannibalism is correlated with the diminishing of crustacean food materials in the diet. April, May and June were the months when the largest quantities of young Bombay duck were eaten. However, Table III shows that in the degree of prevalence, prawns and shrimps either equalled or exceeded Bombay ducks. This

TABLE II.
Qualitative and Quantitative (Volumetric) composition of the Gut contents of the Bombay duck in River Matlah.

Items of diet.	March.		April.		May.		June.		July.	
	Percentage by volume.	Forms identified.	Percentage by volume.	Forms identified.	Percentage by volume.	Forms identified.	Percentage by volume.	Forms identified.	Percentage by volume.	Forms identified.
Prawns and shrimps.	75.0	<i>Metapenaeus</i> sp. <i>Acetes indicus</i> <i>Acetes</i> sp.	31.2	<i>Leander</i> sp. <i>Metapenaeus</i> sp.	33.4	<i>Leander styliferus</i> <i>Acetes</i> sp.	52.9	<i>Metapenaeus</i> sp. <i>Acetes</i> sp. Mysids.	84.9	<i>Metapenaeus</i> sp.
Bombay duck .. (Young of <i>Harpodon nehereus</i>).	..	....	33.9	....	42.6	....	41.7	....	4.7	....
Other fishes ..	9.4	<i>Mugil parsia</i> <i>Bregmaceros</i> <i>maccllellandi</i>	34.9	<i>Gadusia chapra</i> <i>Anchoviella tri</i> <i>Anchoviella</i> sp. <i>Coilia dussumieri</i> <i>Coilia ramcartii</i> <i>Mugil speigleri</i> <i>Mugil tade</i> <i>Mugil parsia</i>	23.6	<i>Anchoviella tri</i> <i>Coilia dussumieri</i> <i>Pseudapocryptes lanceolatus</i>	2.7	<i>Trichurus haumela</i> , Clupeid larvae	3.1	<i>Coilia</i> sp.
Megalopa larvae	3.2	<i>Varuna litterata</i>	..	....	..	....	0.2	<i>Varuna litterata</i>	5.2	<i>Varuna litterata</i>
Plant matter ..	6.2	Haulms of grass	..	....	0.2	Bits of dried grass	..	....	2.1	Dried Haulms of grass.
Detritus ..	6.2	...	..	..	0.2	...	2.5	....	..	....

TABLE II—Continued.

Qualitative and Quantitative (Volumetric) composition of the Gut contents of the Bombay duck in River Matlah.

Item of diet.	August.		September.		October.		November.		December.	
	Percentage by volume.	Forms identified.	Percentage by volume.	Forms identified.	Percentage by volume.	Forms identified.	Percentage by volume.	Forms identified.	Percentage by volume.	Forms identified.
Prawns and shrimps.	32.7	<i>Leander styliferus</i> <i>Leander tenuipes</i> <i>Metapenaeus lysianassa</i> Mysids.	56.4	<i>Leander styliferus</i> <i>Penaeus</i> sp. <i>Metapenaeus</i> sp. Mysids.	71.7	<i>Acetes indicus</i> <i>Acetes</i> sp.	83.1	<i>Leander styliferus</i> <i>Metapenaeus</i> sp.	81.4	<i>Acetes indicus</i> <i>Acetes</i> sp. Mysids.
Bombay duck .. (Young of <i>Harpodon nehereus</i>).	12.7	....	10.5	....	12.3	....	5.0	....	12.0	....
Other fishes ..	7.2	<i>Stolephorus</i> sp.	8.9	<i>Anchoviella</i> larvae <i>Coilia dussumieri</i> <i>Mugil speigleri</i>	5.3	<i>Pana pana</i>	7.7	<i>Coilia dussumieri</i>	6.6	<i>Coilia</i> sp.
Megalops larvae	37.9	<i>Varuna litterata</i>	17.9	<i>Varuna litterata</i>	3.0	<i>Varuna litterata</i>	4.0	<i>Varuna litterata</i>	..	....
Plant matter ..	3.2	Dried haulms of grass.	3.7	Dried bits of plant.	3.0	Dried fragments of grass.	0.2	<i>Najas</i> sp.	..	....
Detritus ..	6.3	....	2.6	....	4.7	....	..	....	..	....

fact is suggestive of the inference that the fish has no marked preference for its own young, and probably only when the bulk of the available crustacean food species is less, do they feed on their own young. A high percentage of prawns and shrimps in the gut contents has been found to be correlated with less pronounced cannibalism.

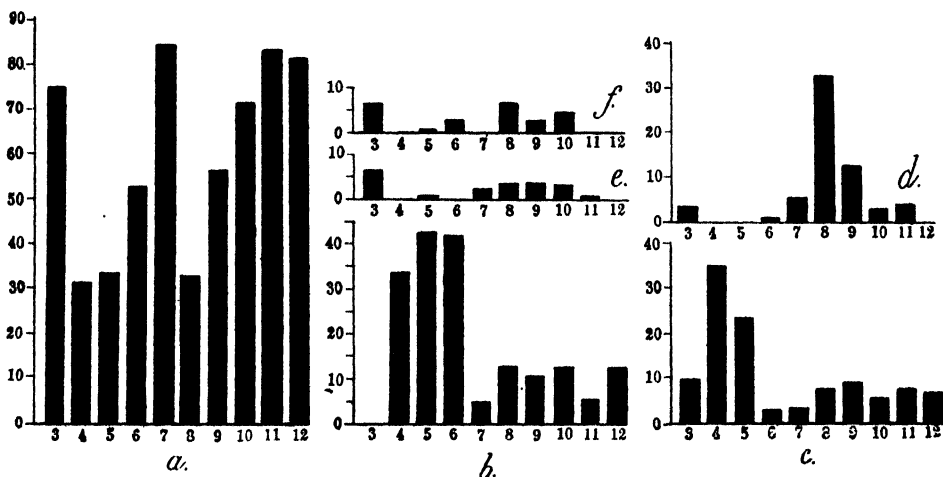


FIG. 2. Histograms showing the monthly variations in the volume of different items of food eaten by the Bombay duck in different months.

- (a) Prawns and shrimps. (b) Bombay duck.
(c) Other fishes. (d) *Megalopa* larvae.
(e) Plant matter. (f) Detritus.

Other Fishes.—This item consists of post-larvae, juveniles and adults of certain estuarine teleosts, which are listed below in the order of their prevalence in the gut contents:

Coilia dussumieri Cuv. & Val.
Coilia ramcartii (Ham.)
Anchoiella tri (Blkr.)
Anchoiella sp.
Mugil parsia Ham.
Mugil speigleri Blkr.
Mugil tade Forsk.
Trichiurus haumela (Forsk.)
Gadusia chapra (Ham.)
Pama pama (Ham.)
Bregmaceros maclellandi Thompson
Pseudapocryptes lanceolatus Bloch & Schn.

Only young ones were generally seen to have been eaten. However, several adult and half grown *Coilia dussumieri* and *C. ramcartii* have also been found. In the month of June, a 22.0 cm. long specimen was observed to have consumed a 22.5 cm. long *Trichiurus haumela*. The prey was found to lie folded in two in the stomach. Only a single semi-digested specimen assignable to *Bregmaceros maclellandi* was found in the gut contents during this investigation. This specimen was observed in the month of March in a 15 cm. long specimen.

Table II and Fig. 2 show that in no month except April and May did these fishes constitute more than 9.4% of the total gut contents. In April and May they formed 34.9% and 23.6% of the total food consumed and 36.9% and 27.3% of the fish

examined had consumed them. As seen in the occurrence of young ones of the Bombay duck, in the gut contents these are months when the quantity of crustacean food eaten was low.

The gut contents analysis indicated that only small quantity of fishes other than its own young ones are eaten and their prevalence in the diet is not high. So it appears that the Bombay duck is not a major enemy of the commercially important fishes in the estuary.

Megalopa larvae.—This item consisted almost entirely of larvae of the common crab, *Varuna litterata*. The occurrence of myriads of these in the Hooghly during the rainy season has been referred to by Chopra (*op. cit.*); and similar swarming has been observed in the River Matlah also during the monsoons. A tow net dragged in the river during this period, especially roundabout the full moon and new moon periods will get almost choked with millions of these.

August and September were the months when the largest quantities of these were eaten by the fish (Tables II and III, Fig. 2). In August 46.9% of the fish examined had fed on this item and it constituted 37.9% of the total gut contents. In September, 17.9% of the gut contents consisted of *Megalopa* larvae and 24%

TABLE III.

The Prevalence (%) of Diet Constituents in the Gut contents of Bombay duck.

Diet constituents.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Prawns and shrimps	75.0	34.8	48.5	57.5	87.9	46.9	52.0	78.9	91.3	86.7
Bombay duck ..	..	34.8	48.5	47.5	4.9	15.6	9.3	15.2	6.4	13.3
Other fishes ..	9.4	36.9	27.3	5.0	4.9	9.4	8.0	6.1	10.6	6.7
<i>Megalopa</i> larvae ..	3.2	..	..	2.5	19.5	46.9	24.0	3.0	4.2	..
Plant matter ..	6.3	..	3.0	..	2.4	6.2	4.0	3.0	4.3	..
Detritus ..	6.2	..	3.0	2.5	..	9.4	4.0	15.2	..	..

of the fish examined had eaten them. In April, May and December they were entirely absent in the gut contents and during the other months they never constituted more than 5.2% of the bulk of its food.

Plant matter.—This item of the gut contents consisted mainly of bits of dried grass and only in one instance has fresh plant matter (*Naias* sp.) been noticed. It is only rarely consumed and only 2.9% of the guts examined contained it, forming 1.9% of the total gut contents. Thus it appears that plant matter is only accidentally consumed while the fish feeds on its major food items. March and July–October were the periods when significant quantities of it were eaten and these are the periods of floods (*bura barsal*) when the water in the river has larger quantities of floating plant matter. In other months it occurred either in very small quantities or was totally absent.

Detritus.—Detritus consisting of sand grains or mud and small quantities of decayed organic matter has also been occasionally found in the gut contents. 4% of the specimens had this item in their guts and it constituted 2.3% of the total gut contents. From the low percentage by volume and occurrence, it appears that like plant matter, detritus is also only accidentally consumed. The presence of detritus and sand grains in the stomach is often interpreted as indicative of bottom feeding habits. But the occasional nature of its presence in the guts of the Bombay duck renders such a conclusion unsafe, even though it is quite possible that the zone of feeding is the bottom or mid-waters. Moreover, the estuarine waters contain considerable quantities of detritus in suspension, and it is very likely that along with other food materials detritus may have also been accidentally consumed.

It might also have come from the guts of prawns and other bottom feeding fishes like the mullets consumed by the fish. In March, April and August–October, which are periods when the estuary is flooded, significant quantities of detritus were present, but in other months it was either absent or was seen in very small quantities.

SUMMARY.

The food and feeding habits of the Bombay duck in the River Matlah was determined by the examination of gut contents. These studies clearly indicate that the fish is strongly carnivorous in feeding habits and prawns and shrimps form the most important item of its food. Smaller prawns such as *Leander*, shrimps like *Acetes* and Mysids were the more common crustacean food materials. During the major part of the year, prawns and shrimps constituted the bulk of the diet. Second in importance as an item of food of the fish is its own young ones. Cannibalistic habits have been observed in fishes 6.6 cm. and above in length. This habit has been found to be more pronounced during April, May and June. Other fishes such as *Coilia*, *Anchoviella* and *Mugil* formed the other items of importance in its dietary. April and June were the months when these predominated. *Megalopa* larvae were consumed in fairly large quantities, during August and September. Plant matter and detritus occurred in the gut contents in small quantities, probably having been consumed accidentally. No marked fluctuations in the intensity of feeding have been noticed. However, the maturing specimens examined had either very little food in their guts or the guts were empty. So also a large number of young ones examined had empty guts.

Though the Bombay duck feeds on some economically important prawns and fishes, the major part of its diet in the River Matlah consists of organisms of less economic value. It therefore appears, that they are not very harmful to the commercial fisheries of the river.

ACKNOWLEDGEMENTS.

Dr. S. L. Hora, very kindly guided me in this work, and I am grateful to him for the varied help he has afforded me. My thanks are due to Mr. K. K. Tiwari for identifying the prawns and shrimps found in the gut contents of the fish, and to Miss K. K. Sarojini for help in obtaining samples of the fish for study during certain months. I am indebted to the National Institute of Sciences of India for the award of a Research Fellowship which enabled me to undertake this work.

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MUGIL DUSSUMIERI VALENCIENNES AS A SYNONYM OF MUGIL PARSIA HAMILTON—A BIOMETRIC STUDY

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INTRODUCTION.

In 1949, I undertook a survey of the mullet fishing centres of Bengal and made extensive collections of all the available species of mullets with the object of selecting the species most suitable for detailed studies. The mullet known as 'Parse' in Bengal was found to be the most abundant species, but its taxonomic characters showed it to be assignable to *Mugil dussumieri* Valenciennes, not to *M. parsia* Hamilton, which, according to previous records, was the most abundant. A thorough examination of specimens referable to *M. parsia* Ham. from River Hooghly, the type locality of *M. parsia* Ham., the Sundarbans and the Midnapore Coast revealed that none of these agreed fully with the characters attributed to it. There were, however, specimens which answered to the descriptions of both *Mugil dussumieri* Val. and *M. parsia* Ham., but none that could be assigned definitely to *M. parsia*. This raised doubts as to the validity of the species described later. Comparison of my material with specimens designated *M. dussumieri* in the collections of the Zoological Survey of India, confirmed my doubts.* Pillay (1951b) in his study of the scales of the two species, has remarked that *M. dussumieri* may be a synonym of *M. parsia*. With a view to ascertain the systematic position of these species, a comparative study was undertaken. In the absence of type specimens of the two species a comparison of samples of both collected from their type localities, was considered the best means of clarifying their taxonomic status. Therefore samples of *M. parsia* were collected for this study from the Gangetic system and samples of *M. dussumieri* from the Coromandel Coast (Visakhapatnam). The results of this study are detailed below.

* Specimens of *M. parsia* Ham. were not available in the collections of the Zoological Survey of India.

REVIEW OF LITERATURE.

Hamilton (1822) described *Mugil parsia* as 'a mugil with nine rays in the hinder fin of the back; with three prickles and eight soft rays in that below the vent; with the end of the tail fin crescent shaped; with two apertures in each nostril; with the gill covers rounded; with a sloping head; and without stripes on the sides, which are scabrous'. He further stated, in the same account, that the species was very similar to what he considered was *M. albula** (= *dussumieri*; vide Day, 1878); but he gave the following characters to distinguish them:

- (1) *M. albula* (= *dussumieri*) has scarcely any scales on the gill covers.
- (2) The sides are smooth, striped with different shades of silver.
- (3) On the centre of each scale is a slender line.

Of these three characters, the first is the only one that can be considered to be of some diagnostic importance. I have, however, found that scales are present on the gill covers of all the specimens of *M. dussumieri* examined in this study. Another difference between the two species, pointed out by Hamilton, is that *M. parsia* grows to a span in length whereas *M. albula* (= *dussumieri*) grows to a foot in length. Though 'Parse' obtained in the estuarine catches and those brought to the Calcutta markets are usually less than about 5"-6" in length, larger specimens of 8"-9" are caught in appreciable numbers from the lower estuaries during the winter months.

Bleeker's (1852) *M. parsia* has 40-45 L.I. scales and hence cannot be considered a synonym of *M. parsia* Ham. (Günther, 1861). Bleeker himself later (vide Weber and de Beaufort, 1922, p. 252) quoted it as a synonym of *M. axillaris*. Weber and de Beaufort (*op. cit.*) considered *M. parsia* of Bleeker synonymous with *M. seheli* Forsk.

M. dussumieri was described for the first time by Valenciennes (in Cuvier and Valenciennes, 1836). He also observed the close resemblance of the species, in proportions, to Hamilton's *M. parsia*. A comparison of his description with Hamilton's description of *M. parsia* shows that the only distinguishing character observed by him is the adipose thickening of the eyelids which he considered to be very characteristic of *M. dussumieri*. The observations of Jacot (1920) on *M. curema* and Pillay (1953) on *M. tade*, indicate that no diagnostic importance can be attached to this character as the adipose eyelids become prominent only in larger specimens. Moreover, Günther (1861) and Day (1889) have both stated that *M. parsia* has well developed posterior adipose eyelids. Specimens of *M. parsia* examined by me also showed the presence of well developed adipose eyelids, though they are not very prominent in young specimens.

From the description of the two species given in Day's 'Fishes of India' (1878), the following distinguishing characters can be recognised:

Character.	<i>M. parsia</i> .	<i>M. dussumieri</i> .
Scales from snout to 1st Dorsal	21 or 22 rows	18 rows.
Caudal	6 times in total length ..	5½ times in total length.
Head	Width equals its length behind anterior third of eye.	Greatest width equals its height or its length excluding the snout.

* Hamilton (*op. cit.*) in describing the form *M. albula* admitted that his specimen did not entirely agree with the descriptions of *M. albula* by Bonnaterre and Lacépède. *M. albula* was first described by Linnaeus in 1766; and Jordan and Swain (1884) have found that *M. albula* Linn. is synonymous with *M. cephalus* Linn.

In his later work (1889) Day recognised the following differences between the two species:

Character.	<i>M. parsia.</i>	<i>M. dussumieri.</i>
Eye	3½ in length of head ..	About 4-4½ in length of head.
Eye	¾ diameter from end of snout	¾-1 diameter from end of snout.
Eye	1½ diameters apart ..	2 diameters apart.
Height of body	4½ to 4¾ in total length ..	4½-5 in total length.
1st dorsal fin	First two spines about equal length of head behind posterior third of orbit.	First spine longest, equaling length of head behind middle of eye and rather higher than 2nd dorsal.
1st dorsal fin	Commences opposite 11th L.I. scale.	Commences opposite 9th L.I. scale.
Third spine of anal fin	¾ length of head ..	¾ length of head.
Anal fin	Not more than ¼ before 2nd dorsal.	¼ before 2nd dorsal.
L.I. scales	34-35	29-31

The formation of the 3rd anal spine from a ray in *M. curema* (vide Jacot, *op. cit.*) corresponds to that observed by Pillay (1953) in *M. tade*. The 3rd anal spine in the young of *M. parsia* is not recognisable in its adult form, but has the appearance of an unbranched ray, which ossifies as the fish grows. Moreover, in the course of this growth, the base of the anal fin is gradually covered with densely arranged scales which are not so clearly seen in the younger stages. It is likely therefore that an error of judgement in measuring the length of the spine would vitiate the relative proportion of the spine length in head length as a reliable diagnostic character.

The samples of *M. parsia* examined in this study do not give support to Day's (1889) observation that in *M. parsia* the first 2 spines of the 1st dorsal are of equal length. In all the specimens examined by me the 1st spine was found to be longer than the 2nd. It might be of interest here to note that Day's (1889) description of *M. parsia* shows some notable differences from his own earlier description of the species from the coast of Malabar (Day, 1865*b*), where he had stated that (1) the pectoral fin extends to the 8th L.I. scale, (2) D_1 commences opposite the 10th L.I. scale, and (3) D_2 commences opposite the 21st L.I. scale.

Weber and de Beaufort (*op. cit.*) have not recognised *M. parsia* as a species occurring in the Indo-Australian Archipelago. Even from the Indian coast there are very few records of the species after Hamilton described it from the Ganges. Day (1865*a* and *b*) has recorded it from Malabar and thereafter Jacob and Menon (1947) in their list of the copepod-feeding fishes of the West Coast, and Sorley (1948) in his report of the Fish and Fisheries of the Bombay Coast have included this species. Bapat and Bal (1952) in a recent paper on the food of some young fishes have recognised *M. parsia* and *M. dussumieri* as two separate species occurring on the Bombay coast.

MORPHOMETRY AND BIOMETRIC COMPARISON.

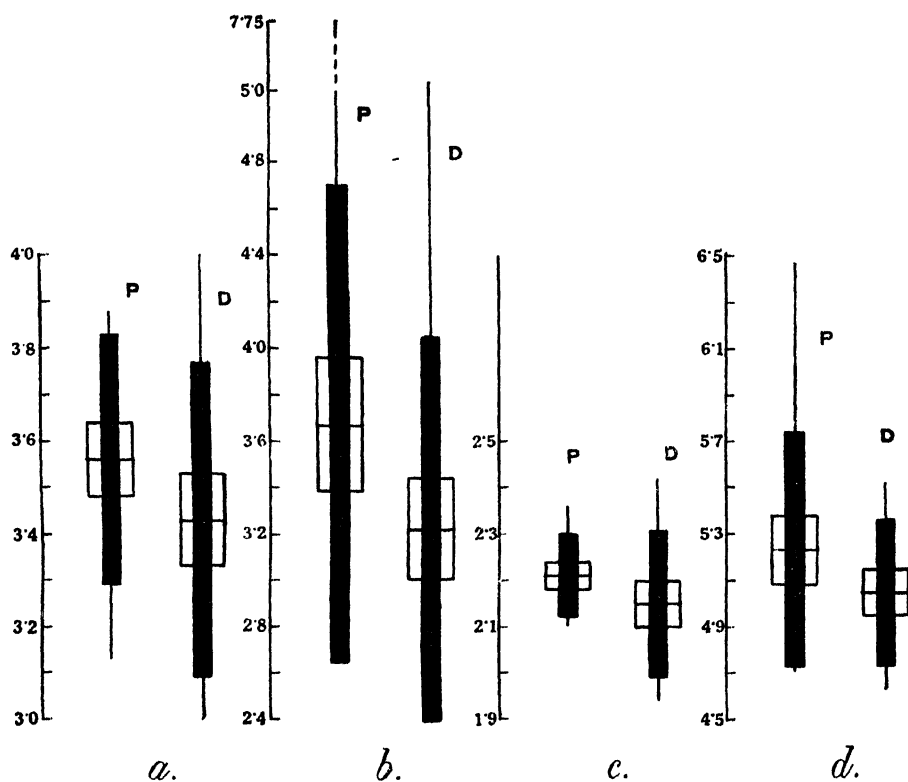
The morphometric characters of 50 specimens of *M. parsia* collected from the Gangetic system and 50 specimens of *M. dussumieri* collected from the Coromandel Coast (Visakhapatnam) were examined in detail. The characters considered to be of diagnostic importance by Day, Günther and Weber and de Beaufort were studied for the purpose as shown below:

1. Length of head in total length.
2. Length of head in standard length.

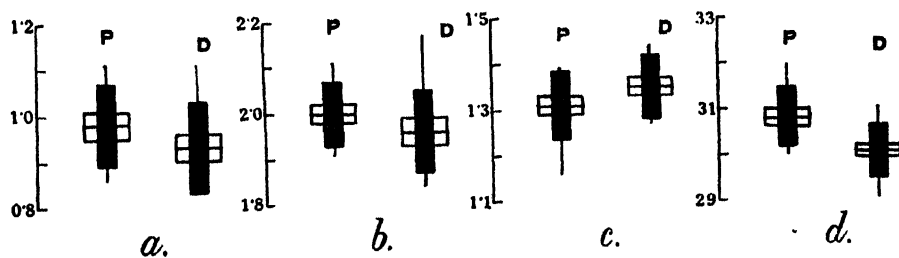
TABLE I.
Biometrical data for *M. parsia* Ham. and *M. dussumieri* Val.

Character.	<i>M. PARSIA.</i>					<i>M. DUSSUMIERI.</i>					σd	t	p
	N.	Range.	Mean.	σ	S.E.	N.	Range.	Mean.	σ	S.E.			
Total length } Length of head }	50	4.62- 5.34	4.97480	0.16310	0.02307	50	4.60- 5.30	4.93520	0.16450	0.02326	0.03276	1.20879	<0.2
Standard length } Length of head }	50	3.69- 4.36	4.00071	0.15582	0.02204	50	3.67- 4.24	3.95480	0.14890	0.02106	0.03049	1.50560	<0.1
Total length } Height of body }	42	4.78- 6.38	5.08762	0.41785	0.06447	50	4.53- 5.51	4.88560	0.23624	0.03341	0.21954	0.92020	<0.3
Standard length } Height of body }	42	3.81- 5.09	4.13905	0.92380	0.14254	50	3.59- 4.43	3.91680	0.19113	0.27030	0.32249	0.68917	<0.4
Length of head } Diameter of eye }	50	3.13- 3.88	3.55800	0.27235	0.03852	50	3.00- 4.00	3.43000	0.34032	0.04813	0.06164	2.08955	<0.02
Inter-orbital distance } Diameter of eye }	50	1.38- 1.76	1.60840	0.09420	0.01332	50	1.33- 1.88	1.59720	0.13134	0.01857	0.02285	0.49015	<0.6
Snout } Diameter of eye }	50	0.86- 1.11	0.97840	0.09065	0.01282	50	0.83- 1.11	0.93310	0.09954	0.01408	0.01904	2.37899	<0.02
Diameter of eye } Anterior adipose eyelid }	50	4.00- 10.33	6.38200	1.36750	0.19339	50	3.45- 9.33	6.43040	1.78040	0.25263	0.31811	0.15215	<0.8
Diameter of eye } Posterior adipose eyelid }	50	2.83- 7.75	3.66670	1.02908	0.14553	50	2.55- 5.14	3.22280	0.82598	0.11681	0.18660	2.37889	<0.02
Length of head } Height of head }	50	1.44- 1.61	1.52600	0.17646	0.24955	50	1.47- 1.68	1.57160	0.04849	0.00686	0.24964	0.18266	<0.8
Length of head } Width of head }	50	1.43- 1.59	1.49160	0.18122	0.25628	50	1.42- 1.59	1.51520	0.49981	0.07068	0.07518	0.31391	<0.7

Length of head } Inter-orbital distance }	50	2.10-2.36	2.21480	0.09426	0.01333	50	1.94-2.42	2.15360	0.15937	0.02254	0.02619	2.33677	<0.02
Length of head } Length of pectoral fin }	50	1.16-1.39	1.31125	0.07498	0.01060	50	1.27-1.44	1.34916	0.06686	0.00946	0.01421	2.66880	<0.01
Length of head } Length of caudal peduncle }	50	1.19-1.65	1.37280	0.10488	0.01483	50	1.23-1.60	1.42920	0.30062	0.04251	0.04502	1.25278	<0.2
Length of head } Least ht. of caudal peduncle }	50	1.37-2.23	1.98240	0.16404	0.02320	50	1.74-2.16	1.95080	0.09570	0.01353	0.02686	1.17647	<0.2
Length of caudal peduncle } Least ht. of caudal peduncle }	50	1.13-1.75	1.44800	1.19361	0.02738	50	1.23-1.53	1.37000	0.39361	0.55664	0.06203	1.25746	<0.2
Total length } Length of caudal fin }	50	4.71-6.47	5.23240	0.51303	0.07255	50	4.63-5.52	5.04480	0.31539	0.04460	0.08517	2.20265	<0.02
Standard length } Snout to D ₁ }	50	1.91-2.11	1.99520	0.06904	0.00976	50	1.84-2.17	1.95720	0.09051	0.01280	0.01610	2.36025	<0.02
Origin of anal fin in relation to D ₂	48	1.78-2.17	1.94417	0.09601	0.01386	50	1.69-2.29	1.92280	0.12174	0.01722	0.02221	0.96218	<0.3
Pre-dors	46	20-21	20.52	0.58352	0.08603	26	20-21	20.31	0.47064	0.09230	0.16784	1.25119	<0.2
L.I. scale	48	30-32	30.79	0.65092	0.09395	50	29-31	30.04	0.60470	0.08552	0.29100	2.58420	<0.01



TEXT-FIG. 1. Graphs showing the variations in,
 (a) diameter of eye in length of head,
 (b) posterior adipose eyelid in diameter of eye,
 (c) inter-orbital distance in length of head, and
 (d) length of caudal fin in total length.
 Abbreviations: P. = *M. parsia*; D. = *M. dussumieri*.



TEXT-FIG. 2. Graphs showing the variations in,
 (a) diameter of eye in length of snout,
 (b) distance from snout to D₁ in standard length,
 (c) length of pectoral fin in length of head, and
 (d) number of L.l. scales.
 Abbreviations: P. = *M. parsia*; D. = *M. dussumieri*.

3. Height of body in total length.
4. Height of body in standard length.
5. Diameter of eye in length of head.
6. Diameter of eye in inter-orbital distance.
7. Diameter of eye in length of snout.
8. Width of anterior adipose eyelid in diameter of eye.
9. Width of posterior adipose eyelid in diameter of eye.
10. Height of head in length of head.
11. Width of head in length of head.
12. Inter-orbital distance in length of head.
13. Length of pectoral fin in length of head.
14. Length of caudal peduncle in length of head.
15. Least height of caudal peduncle in length of head.
16. Least height of caudal peduncle in length of caudal peduncle.
17. Length of caudal fin in total length.
18. Distance from snout to D_1 in standard length.
19. Origin of anal fin in relation to the soft dorsal (base of anal in advance of D_2 , in entire base of anal).
20. Number of pre-dorsal scales.
21. L.I. scales.

The ranges of variation of the above characters studied are incorporated in Table I.

The methods of comparison consisted of (1) a preliminary determination of intergradation of characters, (2) the determination of significance of observed differences, and (3) the assessment of taxonomic status as followed by Pillay (1951a.)

The range of characters clearly showed a high degree of intergradation between the samples representing the two species. To determine the significance of the observed differences, a biometrical comparison of the data was made following the procedure recommended by Simpson and Roe (1942). The results are presented in Table I.

The characters that were found to have the value of p less than 0.1 (i.e., those characters in which the likelihood of the observed differences appearing at random, due to mere chance, was found to be less than 10 in 100), were analysed again by the graphical method suggested by Hubbs and Perlmutter (1942), in order to obtain a clearer picture of the significance of the differences obtained (Text-figs. 1 and 2). It was found from this that only two characters, *viz.*, (1) the proportion of the length of the pectoral fin in length of the head and (2) the number of L.I. scales, showed any significant differences. In order to measure the degree of divergence showed by the two samples in respect of these two characters and to thus determine whether the divergence is of specific magnitude, the method employed by Ginsburg (1938) was used. It was found that the divergence between the two samples in respect of the former character was 62% and the latter, 68% (Tables II and III). It may

TABLE II.

Table showing the intergradation (and divergence) of the two species in respect of the length of pectoral fin in length of head.

Species.	Length of head/Length of pectoral fin.					
	1.16-1.20	1.21-1.25	1.26-1.30	1.31-1.35	1.36-1.40	1.41-1.45
<i>M. parsia</i> ..	4	4	32	40	20	..
<i>M. dussumieri</i> ..	..	..	20	36	36	8

Intergradation .. 38%
Divergence .. 62%

TABLE III.

Table showing the intergradation (and divergence) of the two species in respect of the number of L.I. scales.

Species.	L.I. Scales.			
	29	30	31	32
<i>M. parsia</i> .. ..	..	44	52	4
<i>M. dussumieri</i> ..	16	64	20	..

Intergradation .. 32%

Divergence .. 68%

thus be seen that the differences observed between the two samples are not of specific magnitude. Since, *M. parsia* Hamilton was described earlier than *M. dussumieri* Valenciennes, the name *M. parsia* Ham. has priority, and *M. dussumieri* Val. has to be considered its synonym.

According to Ginsburg (*op. cit.*) two closely related populations are to be considered separate races if the average intergradation of character showing the greatest divergence is between 30% and 40%. In this study, it was found that the two characters showing significant differences, *viz.*, the proportion of the length of pectoral fin in length of head, and the number of L.I. scales, intergrade to the extent of 38% and 32% respectively. Therefore, the samples of *M. parsia* examined from the Gangetic system of rivers in Bengal and from the Coromandel Coast (Visakhapatnam) may be considered to represent two separate racial stocks.

SYNONYMY AND DISTRIBUTION.

The synonyms of *Mugil parsia* Hamilton are as follows:

- Mugil parsia* .. Hamilton, *Fish. Ganges*, 1822, p. 215, pl. XVII, f. 71.
 Cuvier and Valenciennes, *Hist. Nat. Poiss.*, 11, 1836, p. 144.
 (Bleeker, *Nat. Tij. Ned. Ind.*, 1852, 3, p. 166—not synonym.)
 Günther, *Cat. Brit. Mus.*, 3, 1861, p. 426.
 Day, *Fish. Malabar*, 1865, p. 142; *Fish. India*, 1878–1888, p. 350, pl. LXXV, f. 2; *Fauna Brit. India—Fishes*, 2, 1889, p. 344.
- Mugil albula* ? .. Hamilton, *Fish. Ganges*, 1822, p. 218 (not Bonnaterre; not Lacépède).
- Mugil dussumieri* .. Cuvier and Valenciennes, *Hist. Nat. Poiss.*, 11, 1836, p. 147.
 Day, *Fish. India*, 1878–1888, p. 352, pl. LXXIV, f. 4; *Fauna Brit. India—Fishes*, 2, 1889, p. 347.
 Max Weber, *Nova Guinea*, 5 *Zool. Livr.*, 2, 1908, p. 243; *Nova Guinea*, 9, (1913), p. 569.
 McCulloch, *Check list of fish of New South Wales*, Pt. II, 1919, p. 38; *Rec. Austr. Mus.*, 13, (4), 1921, p. 126.
 Weber and de Beaufort, *Fish. Indo-Austr. Arch.*, 4, 1922, p. 235.
 Fowler, *Bull. B. P. Bishop Mus.*, 22, 1925, p. 7; *Mem. B. P. Bishop Mus.*, 10, 1928, p. 122.
 Roxas, *Philipp. J. Sci.*, 54 (3), 1934, p. 401.
- Mugil cantoris* .. Bleeker, *Beng. en Hind.*, p. 100.
 Günther, *Cat. Brit. Mus.*, 3, 1861, p. 430.
- Mugil javanicus* .. Bleeker, *Nat. Tij. Ned. Ind.*, 3, 1852, p. 701 (nomen nudum).
- Mugil sundanensis* .. Bleeker, *Ibid.*, 4, 1853, p. 265; *Ibid.*, 16, 1858–1859, p. 276.
Act. Soc. Sc. Indo-neerl., 8, 1860; *Dertiende Bijdr. Vischfauna Borneo*, p. 45.
 Günther, *Cat. Brit. Mus.*, 3, 1861, p. 425.
 Day, *Fish. Malabar*, 1865, p. 138.
 Macleay, *Proc. Linn. Soc.*, N. S. Wales, 7, 1882, p. 362.

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Bull. U.S. Bur. Fish., **26**, 1906, p. 59.
 Jordan and Seale, *Bull. Bur. Fish. Wash.*, **31**, (1906) 1907,
 p. 11.
Mugil brachysoma .. Bleeker, *Nat. Tij. Ned. Ind.*, **9**, 1855, p. 399. (Juvenis
 abnormis.)
Mugil valenciennesii .. Bleeker, *Ibid.*, **16**, 1858-1859, p. 277.
Mugil subviridis .. Günther, *Cat. Brit. Mus.*, **3**, 1861, p. 423. (? Cuv. & Val.)
Mugil nepalensis .. Günther, *Ibid.*, p. 424.
Mugil meyeri .. Günther, *Ann. Mag. Nat. Hist.*, **9** (4), 1872, p. 439.

In India *M. parsia* is known to occur in the sea and estuaries, from Bombay down the West Coast and up the Coromandel Coast to Visakhapatnam, in Bengal and in the Andamans. Outside India, it has been recorded from Ceylon, Malaya, Siam, the Philippines, Guam, New Guinea and Australia.

SUMMARY.

A study of the mullets collected from the estuarine waters of Bengal shows that *M. dussumieri* Val. agrees closely with the description of *M. parsia* Ham., locally known as 'Parse'; an agreement which Valenciennes himself had observed as long ago as 1836. In view of this, a biometric study of the morphology of both the species has been conducted in order to determine their taxonomic status. As a result of this study it is possible to state that *M. dussumieri* Val. is a synonym of *M. parsia* Ham., and that *M. parsia* collected on the Coromandel Coast and in the Gangetic system may belong to two separate racial stocks.

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ON LATTICE COVERINGS

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1. INTRODUCTION.

Let $X = (x_1, \dots, x_n)$ and $Y = (y_1, \dots, y_n)$ be two points in the n -dimensional Euclidean space R_n . We shall use the usual vector notation to denote the points $(x_1 + y_1, \dots, x_n + y_n)$ and $(\lambda x_1, \dots, \lambda x_n)$, λ real, by the symbols $X + Y$ and λX , respectively. If S and T are two sets of points in R_n , we shall use the symbol $\lambda S + \mu T$ for the set of points $\lambda X + \mu Y$ with the points X and Y lying in S and T respectively. By $|X|$ we shall mean $(x_1^2 + \dots + x_n^2)^{\frac{1}{2}}$, the distance of X from the origin O .

Let K be any bounded or unbounded set and let A be a lattice of points $X = (x_1, \dots, x_n)$, where

$$x_h = \sum_{k=1}^n a_{hk} u_k; \quad h = 1, \dots, n; \quad u_k = 0, \pm 1, \pm 2, \dots$$

and the coefficients a_{hk} are real and the determinant $d(A) = \left| |a_{hk}| \right| \neq 0$. We shall call A a *covering lattice* for K if every point of R_n belongs to the set $K + A$.

The upper bound of the determinants $d(A)$ extended over all covering lattices A for K will be called the *covering constant* of K and will be denoted throughout by $c(K)$ or by c when there is no danger of confusion.

Let K be a closed bounded set with non-zero Jordan measure $V(K)$ and let B be a closed bounded convex body with Jordan volume $V(B)$. We say that there is a *lattice covering of B by u sets K* if there exists a lattice A (not necessarily homogeneous)² such that every point of B belongs to the set $K + A$ and such that there are exactly u sets $K + X$, with X a point of A , which have a point in common with B .

Let $u(B, K)$ denote the smallest number u for which there is a lattice covering of B by u sets K . Then the *density* $\mathfrak{S}(B, K)$ of the most economical lattice covering of B by K is defined by the relation

$$\mathfrak{S}(B, K) = u(B, K) V(K) / V(B) \quad \dots \quad (1)$$

When K is a convex body a result of Hlawka (1949, Satz 1 and Satz 26 folgerung) states that $\lim_{\lambda \rightarrow \infty} \mathfrak{S}(\lambda B, K)$ exists and is in fact equal to $V(K)/c(K)$,

independent of the choice of B . By a slight modification of Hlawka's argument it is easy to prove that this result is valid for any closed bounded set K with an inner point. This limit will be called the *density of the best lattice covering of space by K* and will be denoted by the symbol $\mathfrak{S}(K)$.

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² i.e. A may be a set of the type $A^* + A$, where A^* is a lattice of the type defined earlier and A is a point not in A^* .

A few years ago, Hlawka (1949, Satz 2) proved that for any closed bounded convex body K with a centre, we have

$$\mathfrak{S}(K) \leq n^n. \quad \dots \quad (2)$$

Rogers (1950) improved the above to

$$\mathfrak{S}(K) \leq 3^{n-1}. \quad \dots \quad (3)$$

Bambah and Roth (1952) have shown that if K is further supposed to be symmetrical about the co-ordinate plane, then

$$\mathfrak{S}(K) \leq \frac{\pi}{3\sqrt{3}} \frac{n^n}{n!} \sim e^n \left(\frac{\pi}{54n} \right)^{\frac{1}{2}} \text{ as } n \rightarrow \infty. \quad \dots \quad (4)$$

When K is a sphere Davenport (1952) has proved that

$$\mathfrak{S}(K) < (1.15)^n, \quad \dots \quad (5)$$

while Bambah and Davenport (1952) have proved that

$$\mathfrak{S}(K) > \frac{1}{3} - \epsilon_n, \quad \dots \quad (6)$$

where $\epsilon_n \rightarrow 0$ as $n \rightarrow \infty$.

If K is a bounded convex body in two dimensions, it follows from certain results of Fary (1950) that $c(K)$ is equal to the area of the largest symmetrical hexagon contained in K .

Our object in this paper is to prove some general results about $c(K)$ and certain related lattices for sets K , belonging to more general types than that of closed, bounded and convex bodies.

It may be relevant to remark that there is a close relation between covering lattices and certain problems in the Theory of Numbers. For example, Davenport (1951) has recently obtained the following remarkable theorem.

Let $L_1(x, y) = \alpha x + \beta y$ and $L_2(x, y) = \gamma x + \delta y$ be two linear forms with real coefficients and determinant $\Delta = \begin{vmatrix} \alpha & \beta \\ \gamma & \delta \end{vmatrix} \neq 0$. Then there exist real numbers x_0, y_0 such that

$$|L_1(x + x_0, y + y_0) L_2(x + x_0, y + y_0)| > \frac{1}{128} \Delta \quad \dots \quad (7)$$

for all integers (x, y) .

In the covering notation the above theorem can be rewritten as follows. Let K be the body $|xy| \leq 1$. Then $c(K) < 128$. Prasad (unpublished) and Cassels (1952) have proved (7) with better constants.

2. K CLOSED AND BOUNDED.

In this section our main object is to prove—

THEOREM 1: *Let K be a closed bounded set with the origin O in its interior. Then there exists a covering lattice Λ for K such that*

$$d(\Lambda) = c(K). \quad \dots \quad (8)$$

As O is an inner point of K , it contains a sphere C_i with the centre at the origin. Since every covering lattice of C_i is also a covering lattice for K , we have

$$c = c(K) \geq c(C_i) > 0. \quad \dots \quad (9)$$

On the other hand, K being bounded is contained in a finite sphere C_* with the centre at the origin so that

$$c(K) \leq c(C_*) \leq V(C_*), \quad \dots \quad (10)$$

where $V(C_*)$ is the volume of C_* . Thus c is a non-zero finite number.

By the definition of c , there exists an infinite sequence $A^{(1)}, A^{(2)}, \dots$ of covering lattices (not necessarily all different) of K such that $d(A^{(i)}) \rightarrow c$ as $i \rightarrow \infty$. Without loss of generality we can suppose that for each i

$$\frac{c}{2} < d(A^{(i)}) \leq c. \quad \dots \quad (11)$$

It was shown by Mahler (1946, theorem 1) that every lattice A in R_n has a reduced basis Y_1, \dots, Y_n such that

$$|Y_1| \dots |Y_n| \leq \gamma_n d(A), \quad \dots \quad (12)$$

where γ_n is a constant depending only on n . Let $Y_1^{(i)}, \dots, Y_n^{(i)}$ be such a reduced basis of the lattice $A^{(i)}$ defined above. Then using the inequalities (11) and (12) we have

$$\frac{c}{2} < d(A^{(i)}) \leq |Y_1^{(i)}| \dots |Y_n^{(i)}| \leq \gamma_n d(A^{(i)}) \leq c\gamma_n. \quad \dots \quad (13)$$

We now prove

LEMMA 1: For each i and each $k = 1, \dots, n$ we have

$$|Y_k^{(i)}| < 4\gamma_n \rho, \quad \dots \quad (14)$$

where ρ is the radius of the smallest sphere with the centre at the origin that contains the set K .

Proof: Suppose, for example,

$$|Y_n^{(i)}| \geq 4\gamma_n \rho.$$

Then using relation (13) we have

$$|Y_1^{(i)}| \dots |Y_{n-1}^{(i)}| \leq \frac{c}{4\rho}. \quad \dots \quad (15)$$

Now let $P^{(i)}$ be the fundamental cell of $A^{(i)}$ spanned by $Y_1^{(i)}, \dots, Y_n^{(i)}$. Let Π be the face containing $O, Y_1^{(i)}, \dots, Y_{n-1}^{(i)}$. Let λ be the perpendicular distance of Y_n from Π . Then, using (13) and (15), we get

$$\frac{c}{2} < d(A^{(i)}) = V(P^{(i)}) \leq \lambda |Y_1^{(i)}| \dots |Y_{n-1}^{(i)}| \leq \lambda \frac{c}{4\rho}; \quad \dots \quad (16)$$

here $V(P^{(i)})$ denotes the volume of $P^{(i)}$. From (16) it is clear that

$$\lambda > 2\rho. \quad \dots \quad (17)$$

Let Π_1 and Π_2 be the hyperplanes parallel to Π at distances ρ and $\lambda - \rho$ from it. Then P' the part of $P^{(i)}$ intercepted between Π_1 and Π_2 has a non-zero volume $V(P')$. Since $A^{(i)}$ is a covering lattice for K and so also for the sphere $C: \frac{|X|}{\rho} \leq 1$,

which contains K , every point of P' lies in the set of spheres $C+A^{(i)}$. Therefore

$$\begin{aligned} 0 < V(P') &\leq \sum_{A \in \mathcal{A}^{(i)}} V\{(C+A) \cap P'\} \\ &= \sum_{A \in \mathcal{A}^{(i)}} V\{C \cap (P'+A)\} \\ &\leq V_1 + V_2, \quad \dots \quad \dots \quad \dots \quad (18) \end{aligned}$$

where V_1 is the volume of the part of C which lies to the side of Π_1 away from O and V_2 is the volume of the part of C to the side of $-\Pi_1$ away from O . As the distance of Π_1 from O is equal to ρ , while C is a sphere of radius ρ , it is clear that both V_1 and V_2 are equal to zero, which is in contradiction to (18). This proves the lemma.

By (11) and (14) it follows from a result of Mahler (1946, Theorem 2) that there exists an infinite subsequence of $\{\mathcal{A}^{(i)}\}$ which converges to a lattice \mathcal{A} with $d(\mathcal{A}) = c(K) = c$. Without loss of generality we can suppose that the sequence $\{\mathcal{A}^{(i)}\}$ itself converges to the lattice \mathcal{A} . We now complete the proof of Theorem 1 by proving that \mathcal{A} is a covering lattice for K .

Let Z be any point in R_n and let L be a lattice. We observe that Z lies in the set $K+L$ if and only if L has a point in the set $Z+\bar{K}$, where the set \bar{K} is the image of K in the origin O .

Now, since each $\mathcal{A}^{(i)}$ is a covering lattice for K , it follows that for any point Z in R_n each $\mathcal{A}^{(i)}$ has a point $X^{(i)}$, say, in the set $Z+\bar{K}$. As $Z+\bar{K}$ is closed and bounded, it is clear that there is an infinite subsequence of $\{X^{(i)}\}$ which converges to a point X lying in the set $Z+\bar{K}$. Because of the boundedness of the lattices $\mathcal{A}^{(i)}$ it is easy to see that X must be a point of \mathcal{A} . Thus for every point Z in R_n , \mathcal{A} has a point X in the set $Z+\bar{K}$ and the theorem follows.

DEFINITION: If \mathcal{A} is a covering lattice for a set K and if $d(\mathcal{A}) = c(K)$, then we shall call \mathcal{A} a *maximal covering lattice* for K .

We next prove

THEOREM 2: *If K is a closed and bounded set and if \mathcal{A} is a maximal covering lattice for K , then K has n independent points on its boundary which are just covered, i.e., which do not lie in the interior of any $K+X$ with X in \mathcal{A} .*

Proof: Suppose K does not contain n independent points which are just covered. Denote by Π the set of all points of K which are just covered. Let L be the linear space of lowest dimension f ($0 \leq f \leq n-1$) which contains Π . Let S be the set of all points X_i of \mathcal{A} for which the set $K+X_i$ contains a point of Π . Then the set S must lie in L , for otherwise we have a contradiction to the assumption that all points of K which are just covered lie in L . Let M be the linear space of lowest dimension g ($0 \leq g \leq f \leq n-1$) which contains S . Then by Minkowski's method of adoption of lattices we can find a basis Y_1, \dots, Y_n of \mathcal{A} such that Y_1, \dots, Y_g lie in M and generate it, while Y_{g+1}, \dots, Y_n lie outside M . Let P be the fundamental cell, together with its boundary, spanned by Y_1, \dots, Y_n . Then any point A of P is either completely covered (i.e. is an inner point of a set $K+X$, X in \mathcal{A}) or is congruent mod. \mathcal{A} to a point B of Π .

We now observe that since K is bounded, any point B of Π is at a distance greater than a positive number $r(B)$ from all sets $K+X$, where X is a point of \mathcal{A} not in the set S . Consequently, since \mathcal{A} is a covering lattice for K , every point in the open sphere of radius $r(B)$ about B must lie in a set of the type $K+X$, where X is a point of \mathcal{A} lying in S .

Let \mathcal{Z} be the set of all points $\mathcal{E} = (\xi_1, \dots, \xi_n)$, where $0 \leq \xi_i \leq 1$, for all $i = 1, \dots, n$. Since the point $\xi_1 Y_1 + \dots + \xi_n Y_n$ is a point of P , it is either an inner point of a set $K + X$, with X a point of A , or it is congruent mod. A to a point B of Π . We can consequently associate with every point \mathcal{E} of \mathcal{Z} an open sphere $c(\mathcal{E})$ containing \mathcal{E} and a real number $\epsilon(\mathcal{E}) > 0$ such that for all positive $\epsilon < \epsilon(\mathcal{E})$ the points $\xi_1 Y_1 + \dots + \xi_{n-1} Y_{n-1} + \xi_n Y'_n$ for all (ξ_1, \dots, ξ_n) in $c(\mathcal{E})$ lie in the set $K + A'$ where $Y'_n = Y_n(1 + \epsilon)$ and A' is the lattice generated by $Y_1, \dots, Y_{n-1}, Y'_n$. From this it follows easily by the Heine-Borel Theorem that there exists a positive number ϵ^* such that the lattice A^* generated by $Y_1, \dots, Y_{n-1}, Y_n(1 + \epsilon^*)$ is a covering lattice for K . But $d(A^*) = (1 + \epsilon^*)d(A) = (1 + \epsilon^*)c(K) > c(K)$. Thus we get a contradiction which proves the theorem.

3. K CLOSED BUT UNBOUNDED.

In this section we suppose K is an unbounded closed set which contains the origin in its interior and which has Lebesgue measure $V(K)$. We first prove the almost trivial

THEOREM 3: $c(K) \leq V(K)$.

Proof: If $V(K) = \infty$, there is nothing to prove. Therefore, we can suppose $V(K) < \infty$. Let A be a covering lattice for K and P a fundamental cell of A . Since every point of P lies in the set $K + A$, we clearly have

$$\begin{aligned} d(A) = V(P) &\leq \sum_{A \in \mathcal{A}} V\{(K + A) \cap P\} \\ &= \sum_{A \in \mathcal{A}} V\{K \cap (P + A)\} \\ &= V(K) \cap R_n \\ &= V(K), \end{aligned}$$

and the theorem follows.

In the rest of this section we shall suppose $V(K) < \infty$, and our object will be to prove

THEOREM 4: Let K be an unbounded but closed set containing O in its interior and having Lebesgue measure $V(K) < \infty$. Then there exists a lattice A with $d(A) = c(K)$ such that the set of all points of R_n which do not lie in $K + A$ has Lebesgue measure zero.

We shall in the rest of the paper write $K^{(t)}$ for the set of all points of K which lie in the sphere $|X| \leq t$. We shall use the symbol R_t both for $V(K) - V(K^{(t)})$ and for the set $K \cap CK^{(t)}$, i.e. for the set of points of K which do not lie in $K^{(t)}$. In the usual notation we shall write $\delta(X, S)$ for the distance, i.e. $\frac{bd}{Y\epsilon S} |X - Y|$, of the point X from the set S .

If S is closed, it is clear that $X \in S$ if and only if $\delta(X, S) = 0$. Further, A is a covering lattice for S if and only if for every point A of R_n there is a point X of A , such that

$$\delta(A, K + X) = \delta(A - X, K) = 0.$$

Since O is an inner point of K , there is a sphere $C: |X| \leq \rho$, which is contained in K . Consequently

$$0 < c(C) \leq c(K) \leq V(K) < \infty.$$

Thus $c = c(K)$ is a non-zero finite number.

As in §2 there exists an infinite sequence $\Lambda^{(1)}, \Lambda^{(2)}, \dots$ of covering lattices of K such that $d(\Lambda^{(i)}) \rightarrow c$ and such that

$$\frac{c}{2} < d(\Lambda^{(i)}) \leq c. \quad \dots \quad \dots \quad \dots \quad (19)$$

Also $\Lambda^{(i)}$ has a reduced basis $Y_1^{(i)}, \dots, Y_n^{(i)}$, such that

$$\frac{c}{2} < d(\Lambda^{(i)}) \leq |Y_1^{(i)}| \dots |Y_n^{(i)}| \leq \gamma_n d(\Lambda^{(i)}) \leq c\gamma_n, \quad \dots \quad \dots \quad (20)$$

where γ_n is a constant depending only on n .

It is well known that $R_t = V(K) \cdot V(K^{(t)}) \rightarrow 0$ as $t \rightarrow \infty$. Let $t = t_1$ be a fixed number for which $R_{t_1} < \frac{1}{6}c$. We now prove a lemma (lemma 2) very similar to lemma 1 of §2.

Lemma 2: For each i and each $k = 1, \dots, n$, we have

$$|Y_k^{(i)}| < 6\gamma_n t_1. \quad \dots \quad \dots \quad \dots \quad (21)$$

Proof: Suppose, for example, $|Y_n^{(i)}| \geq 6\gamma_n t_1$.

Then from (20), we have

$$|Y_1^{(i)}| \dots |Y_{n-1}^{(i)}| \leq \frac{1}{6} \frac{c}{t_1}. \quad \dots \quad \dots \quad \dots \quad (22)$$

Now let $P^{(i)}$ be the fundamental cell of $\Lambda^{(i)}$ spanned by $Y_1^{(i)}, \dots, Y_n^{(i)}$. Let Π be its face containing the points $O, Y_1^{(i)}, \dots, Y_{n-1}^{(i)}$ and let $V(\Pi)$ be the $(n-1)$ -dimensional volume of Π . Let λ be the perpendicular distance of Y_n from Π . Then, by (20) and (22), we have

$$\begin{aligned} \frac{c}{2} < d(\Lambda^{(i)}) \quad V(P^{(i)}) &= \lambda V(\Pi) \\ &\leq \lambda |Y_1^{(i)}| \dots |Y_{n-1}^{(i)}| \\ &\leq \frac{\lambda c}{6t_1}, \end{aligned}$$

so that

$$\lambda > 3t_1. \quad \dots \quad \dots \quad \dots \quad (23)$$

Let Π_1 and Π_2 be the hyper-planes through the points $\frac{1}{3} Y_n^{(i)}, \frac{2}{3} Y_n^{(i)}$, parallel to Π . Let P' be the part of $P^{(i)}$ intercepted between Π_1 and Π_2 . Then

$$V(P') = \frac{1}{3} V(P^{(i)}) = \frac{1}{3} d(\Lambda^{(i)}). \quad \dots \quad \dots \quad \dots \quad (24)$$

Since $\Lambda^{(i)}$ is a covering lattice for K , every point of P' lies in the set $K + \Lambda^{(i)}$. Consequently, we have

$$\begin{aligned} \frac{1}{6} c &< \frac{1}{3} d(\Lambda^{(i)}) = V(P') \\ &\leq \sum_{A \in \Lambda^{(i)}} V\{(K+A) \cap P'\} \\ &= \sum_{A \in \Lambda^{(i)}} V\{K \cap (P'+A)\} \\ &\leq V_1 + V_2, \quad \dots \quad \dots \quad \dots \quad (25) \end{aligned}$$

where V_1 is the volume of the part of P' which lies on the side of Π_1 away from O and V_2 is the part of P' which lies on the side of $-\Pi_1$ away from O . Since the distance of Π_1 from O is greater than t_1 , it is clear that $V_1 + V_2 \leq R_{t_1}$, so that, by (25) and the definition of t_1 , we have

$$\frac{1}{6}c < V_1 + V_2 \leq R_{t_1} < \frac{1}{6}c,$$

which is a contradiction that establishes the lemma.

From Lemma 2, it follows as in §2 that there exists an infinite subsequence of $\{A^{(i)}\}$ converging to a lattice A with $d(A) = c$. Without loss of generality we can suppose that the sequence $\{A^{(i)}\}$ itself converges to A . Further Y_1, \dots, Y_n , where

$$Y_k = \lim_{i \rightarrow \infty} Y_k^{(i)},$$

is a reduced basis of A .

From inequalities (20) and (21) it is easy to see that the paralleloiped \bar{P} whose vertices are given by $\pm Y_1^{(i)} \pm \dots \pm Y_n^{(i)}$ contains the sphere $|X| \leq 2 \left(\frac{1}{6\gamma_n t_1} \right)^{n-1}$ in its interior. As this sphere is independent of i , we easily deduce that given a fixed sphere C , there are only a finite number of sets of integers (a_1, \dots, a_n) such that there exists a +ve integer i for which the point $a_1 Y_1^{(i)} + \dots + a_n Y_n^{(i)}$ lies in C . Again, since \bar{P} does not contain any point of $A^{(i)}$, except O , in its interior, it is easy to see that the lattices $A^{(i)}$ are bounded in the sense of Mahler (1946, Def. 1).

Since both $K^{(i)}$ and $A^{(i)}$ are bounded it is easy to verify that for every point X of $P^{(i)}$, $\frac{bd}{A\epsilon A^{(i)}} \delta(X, K^{(i)} + A)$ is actually attained. Further, if C is a big enough sphere depending only on t and c , the bd is attained at a point $A^{(i)}$ of $A^{(i)}$ which lies in C . Let C be such a sphere. Let S be the set of integers (a_1, \dots, a_n) such that for some $i = 1, 2, \dots$ the point $a_1 Y_1^{(i)} + \dots + a_n Y_n^{(i)}$ lies in C . As already observed S has only a finite number of its members. Therefore for every X in $P^{(i)}$ we have

$$\frac{bd}{A\epsilon A^{(i)}} \delta(X, K^{(i)} + A) = \min_{(a_1, \dots, a_n) \in S} \delta(X - a_1 Y_1^{(i)} - \dots - a_n Y_n^{(i)}, K^{(i)}). \quad (26)$$

Now define E_k to be the set of points (ξ_1, \dots, ξ_n) , $0 \leq \xi_k \leq 1$, $k = 1, \dots, n$, such that for every $j \geq 1$ the point $\xi_1 Y_1^{(j)} + \dots + \xi_n Y_n^{(j)}$ does not lie in $K^{(j)} + A^{(j)}$. Similarly define E as the set of points (ξ_1, \dots, ξ_n) , $0 \leq \xi_k \leq 1$, $k = 1, \dots, n$, for which the point $\xi_1 Y_1 + \dots + \xi_n Y_n$ does not lie in $K^{(i)} + A$. Then we have

Lemma 3: $E \subseteq E_1 \cup E_2 \cup \dots$

Proof: Let $(\xi_1, \dots, \xi_n) \in E$. Then $\xi_1 Y_1 + \dots + \xi_n Y_n$ does not lie in $K^{(i)} + A$. Therefore,

$$\delta\{(\xi_1 Y_1 + \dots + \xi_n Y_n) - (a_1 Y_1 + \dots + a_n Y_n), K^{(i)}\} > \epsilon > 0$$

for some ϵ and all (a_1, \dots, a_n) in S , i.e. all the points $(\xi_1 - a_1) Y_1 + \dots + (\xi_n - a_n) Y_n$ are exterior points of $K^{(i)}$. Since there are only a finite number of members of S and since $Y_k^{(i)} \rightarrow Y_k$ it follows that there is a j , such that for all $i \geq j$ and all (a_1, \dots, a_n) in S ,

$$\delta\{(\xi_1 Y_1^{(i)} + \dots + \xi_n Y_n^{(i)}) - (a_1 Y_1^{(i)} + \dots + a_n Y_n^{(i)}), K^{(i)}\} > 0.$$

This means that $\xi_1 Y_1^{(i)} + \dots + \xi_n Y_n^{(i)}$ does not lie in $K^{(i)} + A^{(i)}$ for all $i \geq j$, i.e. $(\xi_1, \dots, \xi_n) \in E_j$. From this the lemma follows at once

Lemma 4: Let $F^{(i)}$ be the set of points (ξ_1, \dots, ξ_n) , $0 \leq \xi_k \leq 1$, for which the corresponding points $\xi_1 Y_1^{(i)} + \dots + \xi_n Y_n^{(i)}$ do not lie in $K^{(i)} + A^{(i)}$. Then

$$m_e(F^{(i)}) \leq R_t \cdot \frac{1}{d(A^{(i)})} < \frac{2}{c} R_t, \quad \dots \quad \dots \quad (27)$$

where $m_e(F^{(i)})$ denotes the outer Lebesgue measure of $F^{(i)}$.

Proof: Since $A^{(i)}$ is a covering lattice for K , the parallelepiped $P^{(i)}$ spanned by $Y_1^{(i)}, \dots, Y_n^{(i)}$ is contained in $K + A^{(i)}$. Consequently the points of $P^{(i)}$ which are not contained in $K^{(i)} + A^{(i)}$ are contained in $R_t + A^{(i)}$. Therefore, if we denote by $G^{(i)}$ the set of points of $P^{(i)}$ which do not lie in $K^{(i)} + A^{(i)}$, we have

$$\begin{aligned} m_e(G^{(i)}) &\leq \sum_{A \in A^{(i)}} V\{(R_t + A) \cap P^{(i)}\} \\ &= \sum_{A \in A^{(i)}} V\{R_t \cap (P^{(i)} + A)\} \\ &= V(R_t \cap R_n) \\ &= R_t, \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (28) \end{aligned}$$

and

$$m_e(F^{(i)}) = \frac{1}{d(A^{(i)})} m_e(G^{(i)}) \leq \frac{1}{d(A^{(i)})} R_t < \frac{2}{c} R_t.$$

This proves the lemma.

Now E_i is clearly a subset of $F^{(i)}$. Therefore

$$m_e(E_i) \leq m_e(F^{(i)}) < \frac{2}{c} R_t, \quad \dots \quad \dots \quad \dots \quad (29)$$

From the definition of E_i it is clear that for every $j \geq i$, $E_j \supseteq E_i$. Therefore, writing

$$E' = E_1 \cup E_2 \cup \dots,$$

we have

$$m_e(E) \leq m_e(E') = \lim_{i \rightarrow \infty} m_e(E_i) \leq \frac{2}{c} R_t, \quad \dots \quad \dots \quad \dots \quad (30)$$

If we denote by $H^{(i)}$ the set of points of P the parallelepiped spanned by Y_1, \dots, Y_n which do not lie in $K^{(i)} + A$, it follows that

$$m_e(H^{(i)}) = d(A) m_e(E) \leq \frac{2R_t}{c} d(A) = 2R_t, \quad \dots \quad \dots \quad (31)$$

By taking t large enough we can make R_t as small as we like. This completes the proof of Theorem 4.

We end this section with an example which shows that there exists a K with finite Lebesgue measure for which the possibility that the set of points not lying in $K + A$ be non-empty does in fact arise.

Example: Let K be the set of points (x, y) , where

$$|x| \leq \frac{1}{4}, \quad |y| \leq \frac{1}{2};$$

$$\frac{1}{4} \leq x \leq \frac{3}{8}, \quad \frac{1}{2} \leq y \leq \frac{3}{2}; \quad -\frac{1}{4} \geq x \geq -\frac{3}{8}, \quad -\frac{1}{2} \geq y \geq -\frac{3}{2};$$

$$\frac{3}{8} \leq x \leq \frac{7}{16}, \quad \frac{3}{2} \leq y \leq \frac{5}{2}; \quad -\frac{3}{8} \geq x \geq -\frac{7}{16}, \quad -\frac{3}{2} \geq y \geq -\frac{5}{2};$$

$$\frac{7}{16} \leq x \leq \frac{15}{32}, \quad \frac{5}{2} \leq y \leq \frac{7}{2}; \quad -\frac{7}{16} \geq x \geq -\frac{15}{32}, \quad -\frac{5}{2} \geq y \geq -\frac{7}{2}; \text{ etc.}$$

It is clear that $c(K) = V(K) = 1$. Also there is no covering lattice A , for which $d(A) = 1$, while the lattice $A: x = \xi, y = \eta, \xi, \eta$ integers has determinant 1 and is such that the set of points which do not lie in $K + A$ consists of an enumerable number of lines parallel to the Y -axis and is consequently of measure zero.

4. K A STAR-SET.

In this section we shall suppose that K is a star-set,¹ bounded or unbounded. We shall denote its distance function by $f(X)$. As before, we shall write $K^{(t)}$ for the set of points of K which lie in the sphere $|X| \leq t$, i.e. $K^{(t)}$ is the set defined by

$$f^{(t)}(X) = \max. \left\{ f(X), \frac{|X|}{t} \right\} \leq 1. \quad \dots \quad (32)$$

It is well known that $K^{(t)}$ also is a star-set. We shall denote the volume (not necessarily finite) of K by the symbol $V(K)$.

THEOREM 5: *There exist star-sets K with $V(K) = \infty$ for which (i) $c(K) < \infty$, (ii) $c(K) = \infty$.*

Proof: (i) It follows from the result of Davenport referred to in the introduction that K defined by the inequality $|x_1 x_2| \leq 1$ has the property (i).

(ii) It is well known that if

$$\begin{aligned} x_1 &= \alpha u + \beta v, \\ x_2 &= \gamma u + \delta v \end{aligned}$$

are linear forms with real coefficients and determinant $\Delta = \begin{vmatrix} \alpha & \beta \\ \gamma & \delta \end{vmatrix} \neq 0$ and if α/β is not rational, then for any $\epsilon > 0$ and any real numbers c_1, c_2 there exist integers u, v such that

$$|x_1 + c_1| < \epsilon, \quad |(x_1 + c_1)(x_2 + c_2)| < \frac{1}{4} \Delta. \quad \dots \quad (33)$$

From (33) it is easy to see that the set $K = f(x) = |(x_1^2 x_2)^{\frac{1}{2}}| \leq 1$ has arbitrarily large covering lattices. This means that $c(K) = \infty$ and the theorem is proved.

Our next theorem shows that unlike for convex sets with a centre there is no finite upper bound for $\mathfrak{S}(K) = V(K)/c(K)$ even when K is restricted to the class of bounded star bodies.

¹ We use the notation of Mahler (1946).

THEOREM 6:

$$\frac{\bar{b}d}{K} \frac{V(K)}{c(K)} = \infty,$$

where the upper bound is taken over all bounded star-sets K .

Proof: Let K be the set $|x_1 x_2| \leq 1$. Then $K^{(t)}$, the set of its points lying within a distance t from the origin, is a bounded star-set. Since $K^{(t)} \leq K$, we have

$$c(K^{(t)}) \leq c(K) < 128. \quad \dots \quad (34)$$

Also $V(K^{(t)}) \rightarrow V(K) = \infty$ as $t \rightarrow \infty$. Therefore, by taking t large enough we can make $V(K^{(t)})/c(K^{(t)})$ as large as we like and the theorem follows.

Our next theorem is the central theorem for this section.

THEOREM 7: Let K be an unbounded star body and $K^{(t)}$ the set of its points lying within a distance t from the origin. Then

$$\lim_{t \rightarrow \infty} c(K^{(t)}) = c(K). \quad \dots \quad (35)$$

Proof: It is obvious that for $t_2 > t_1$, $K^{(t_2)}$ contains $K^{(t_1)}$ so that $c(K^{(t)})$ is an increasing function of t . If $c(K^{(t)})$ is not bounded above, then there exist real numbers t such that $K^{(t)}$ and so also K has arbitrarily large covering lattices. This means that $c(K) = \infty$ and since $\lim_{t \rightarrow \infty} c(K^{(t)}) = \infty$ there is nothing to prove. Therefore, we can suppose that $c(K^{(t)})$ is bounded above so that $c(K^{(t)}) \rightarrow$ a limit $c \neq \infty$ as $t \rightarrow \infty$ and have to show that $c(K) = c$. For this it will suffice to prove

(a) For every $c_1 < c$ there is a covering lattice A for K for which $d(A) > c_1$, and (b) there is no covering lattice A of K for which we have $d(A) > c$.

The condition (a) is clearly satisfied since for every $c_1 < c$, there is a t with $c(K^{(t)}) > c_1$ and the maximal covering lattice $A^{(t)}$ of $K^{(t)}$ is a covering lattice for K whose determinant is greater than c_1 .

We prove (b) by *reductio ad absurdum*. We suppose there is a covering lattice A for K , whose determinant $d(A) = c(1 + 2\epsilon)^n$, where $\epsilon > 0$ is a real number.

The lattice $A' = \frac{1}{1+\epsilon}A$ is obviously a covering lattice for the set $\frac{1}{1+\epsilon}K$. Let X_1, \dots, X_n be a basis of A' and let P be the corresponding fundamental cell. Let $X = \alpha_1 X_1 + \dots + \alpha_n X_n$ where $0 \leq \alpha_i \leq 1$ for all $i = 1, \dots, n$ be a point of P . Then there exists a point $A(X) = A$ of A' such that

$$f(X - A) \leq \frac{1}{1+\epsilon}.$$

Since $f(X)$ is continuous we can find an open sphere $C(X)$ with centre at X such that for every point Z of $C(X)$ we have

$$f(Z - A) \leq 1.$$

In this way we can associate an open sphere $C(X)$ and a point $A(X)$ of A' with every point X or P such that all points in $C(X)$ lie in the set $K + A(X)$. As P is a closed bounded set, we can choose a finite number of spheres $C(X)$ which together cover P . This means that we can choose a finite number of points A_1, \dots, A_μ of A' such that P is contained in the union of the sets $K + A_1, \dots, K + A_\mu$. As μ is finite there exists a t such that P is completely contained in the union of the sets $K^{(t)} + A_1, \dots, K^{(t)} + A_\mu$. This means that A' is a covering lattice for $K^{(t)}$. Since

$d(A') = \frac{1}{(1+\epsilon)^n} d(A) > c > c(K^{(t)})$ we get a contradiction and the theorem is completely proved.

We next give three theorems which are consequences of Theorem 7 and are analogous to certain theorems of Mahler (1946) and Davenport and Rogers (1949) for critical determinants of star bodies.

THEOREM 8: *Let K, K_1, K_2, \dots be an infinity of star bodies satisfying the following conditions:—*

- (a) *to every $\epsilon > 0$ there corresponds a positive integer $N(\epsilon)$ such that for all $r \geq N(\epsilon)$, K_r is contained in $(1+\epsilon)K$.*
- (b) *for every $t > 0$ and every $\epsilon > 0$, there exists a positive integer $N(t, \epsilon)$ such that $K^{(t)}$ is contained in $(1+\epsilon)K_r$ for all $r \geq N(t, \epsilon)$. Then*

$$\lim_{r \rightarrow \infty} c(K_r) = c(K). \quad \dots \quad (36)$$

Proof: For r large enough K_r is contained in $(1+\epsilon)K$,

$$\text{therefore} \quad c(K_r) \leq c((1+\epsilon)K_r) = (1+\epsilon)^n c(K_r).$$

Making $\epsilon \rightarrow 0$, we have

$$\limsup_{r \rightarrow \infty} c(K_r) \leq c(K).$$

Again for r large enough $K^{(t)}$ is contained in $(1+\epsilon)K_r$.

$$\text{Therefore} \quad c(K^{(t)}) \leq c((1+\epsilon)K_r) = (1+\epsilon)^n c(K_r).$$

Therefore, on making $\epsilon \rightarrow 0$ and $t \rightarrow \infty$, we get

$$c(K) \leq \liminf_{r \rightarrow \infty} c(K_r),$$

and the theorem follows.

THEOREM 9: *Let $K : f(X) \leq 1$ be a star-set, $g(X)$ an arbitrary distance function and t a positive parameter. Then for the star-sets $K_t(X) : f_t(X) \leq 1$, where*

$$f_t(X) = \max. \{f(X), t^{-1}g(X)\}, \quad \dots \quad (37)$$

we have

$$\lim_{t \rightarrow \infty} c(K_t) = c(K). \quad \dots \quad (38)$$

Proof: Since $f_t(X) \geq f(X)$ for all X and t , it is clear that K_t is contained in K . Also since the set $H : g(X) \leq 1$ is a star-set, there exists a number $\tau > 0$ such that H contains the sphere $|X| \leq \tau$. The sphere $|X| \leq \tau t$ is contained in tH , so that $K^{(\tau t)}$ which is a subset of this sphere lies in tH . Consequently $K^{(\tau t)}$ is contained in K_t . Thus the hypotheses of Theorem 8 are satisfied and (38) follows.

THEOREM 10: *Let $g(x_1, \dots, x_r)$ and $e(x_1, \dots, x_r)$ be distance functions of r variables and let $h(x_{r+1}, \dots, x_n)$ be a distance function of $n-r$ variables, where $1 \leq r \leq n-1$. Then the star bodies in R_n defined by*

$$\{g(x_1, \dots, x_r)\}^{r/n} \{h(x_{r+1}, \dots, x_n)\}^{\frac{n-r}{n}} \leq 1 \quad \dots \quad (39)$$

and

$$\{g(x_1, \dots, x_r)\}^{r/n} \{e(x_1, \dots, x_r) + h(x_{r+1}, \dots, x_n)\}^{\frac{n-r}{n}} \leq 1 \quad \dots \quad (40)$$

have the same covering constant.

Proof: Let K denote the star-set defined by (39) and K' that defined by (40). The substitution

$$\nu x_1 = x_1', \dots, \nu x_r = x_r', \mu x_{r+1} = x_{r+1}', \dots, \mu x_n = x_n',$$

where ν and μ are positive numbers with $\nu^r \mu^{n-r} = 1$ as a substitution of determinant 1. Hence, if K_ν' denotes the star body defined by

$$\left\{ g\left(\frac{x_1}{\nu}, \dots, \frac{x_r}{\nu}\right)^{r/n} \right\} \left\{ e\left(\frac{x_1}{\nu}, \dots, \frac{x_r}{\nu}\right) + h\left(\frac{x_{r+1}}{\mu}, \dots, \frac{x_n}{\mu}\right) \right\}^{\frac{n-r}{n}} < 1 \quad \dots \quad (41)$$

we have

$$c(K_\nu') = c(K') \quad \dots \quad \dots \quad \dots \quad (42)$$

for any ν .

Since g , e and h are distance functions we can write (41) as

$$g(x_1, \dots, x_r)^{r/n} \left\{ \frac{\mu}{\nu} e(x_1, \dots, x_r) + h(x_{r+1}, \dots, x_n) \right\}^{\frac{n-r}{n}} < 1. \quad \dots \quad (43)$$

Now consider any point (x_1, \dots, x_n) of $K^{(t)}$. This point satisfies (39) and g , e , h have upper bounds g_0 , e_0 , h_0 which depend on t but not on ν . We, therefore, have

$$\begin{aligned} g^{r/n} \left(\frac{\mu}{\nu} e + h \right)^{\frac{n-r}{n}} &\leq g^{r/n} h^{\frac{n-r}{n}} + g^{r/n} \left(\frac{\mu}{\nu} e \right)^{\frac{n-r}{n}} \\ &\leq 1 + g_0^{r/n} \left(\frac{\mu}{\nu} e_0 \right)^{\frac{n-r}{n}}. \end{aligned}$$

If ϵ is any positive number, the last expression can be made smaller than $1 + \epsilon$ by taking ν large enough. Hence for a fixed t the body $K^{(t)}$ is contained in $(1 + \epsilon)K_\nu'$ for large ν . Therefore

$$c(K^{(t)}) \leq (1 + \epsilon)^n c(K_\nu') = (1 + \epsilon)^n c(K'),$$

so that

$$c(K^{(t)}) \leq c(K'),$$

and by making $t \rightarrow \infty$

$$c(K) \leq c(K'). \quad \dots \quad \dots \quad \dots \quad (44)$$

But K' is contained in K . Therefore

$$c(K') \leq c(K), \quad \dots \quad \dots \quad \dots \quad (45)$$

and the theorem follows from (44) and (45).

It is easy to verify that the theorem remains valid if in (40) $e + h$ is replaced by $(e^\alpha + h^\alpha)^{1/\alpha}$ where $\alpha > 1$.

As a consequence of this theorem it is interesting to note that for any positive k , the sets

$$K_1: |xy| < 1, \quad \dots \quad \dots \quad \dots \quad (46)$$

$$K_2: |x| (k|x| + |y|) < 1, \quad \dots \quad \dots \quad \dots \quad (47)$$

and

$$K_3: |x| (k|x|^\alpha + |y|^\alpha)^{1/\alpha} < 1, \alpha > 1, \quad \dots \quad \dots \quad (48)$$

have the same covering constant. Further, as the set $K_4 = \{x \mid |x| < \frac{1}{\sqrt{k}}, |xy| < 1$

is contained in K_1 , while K_2 is contained in K_4 , it is interesting to see that the set K_1 has the same covering constant as its subsets $|xy| \leq 1$, $|x| \leq \epsilon$, for all ϵ , however small.

SUMMARY.

Certain general theorems about the covering constant and covering lattices have been obtained for different types of sets in the Euclidean space of n dimensions.

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THE ENERGY LEVELS OF PX

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H. A. Robinson has performed an analysis of the spectrum of PX, and his results are quoted by Charlotte E. Moore (1949). During a theoretical study of the atoms of the CI isoelectronic sequence, the complete results of which will be published shortly in these *Proceedings*, I noticed that Robinson's values of the energy levels of the ground configuration of PX did not give results in accordance with the trend of the isoelectronic sequence. The discrepancy appears to be real. Robinson's values for the level intervals are:

$$\begin{aligned} {}^3P_2 - {}^3P_1 &= 5190 \text{ cm.}^{-1} \\ {}^3P_1 - {}^3P_0 &= 3390 \text{ cm.}^{-1} \end{aligned}$$

In the above-mentioned study I have calculated the values of the spin-orbit interaction integral ζ and the mutual magnetic interaction integral M_0 for the first ten members of the sequence for which the energy levels are known. The expressions for the energy levels were obtained by taking into account the complete spin-orbit interaction, as well as the mutual magnetic interactions. These expressions were then equated to the positions of the energy levels, known from spectroscopic analyses, and the equations were solved for the unknown parameters ζ and M_0 .

Table I gives the values of ζ and M_0 obtained in this manner. It is at once clear that the value of M_0 for PX is too low. Also if we plot the fourth roots of ζ against the atomic number, the points lie fairly closely on a straight line, except the point for PX which lies below the straight line.

TABLE I.

	ζ	M_0
CI ..	32.5	0.07
NI ..	97	0.20
OIII ..	222	0.38
FIV ..	436	0.61
NeV ..	789	1.11
NaVI ..	1304	1.65
MgVII ..	2056	2.63
AlVIII ..	3083	3.75
SiIX ..	4442	4.98
PX ..	5687	2.42

The discrepancy is inexplicable except if we assume that the observed energy levels are in error. I favour this assumption and extrapolate the values of ζ and M_0 for PX. They are:

$$\begin{aligned} \zeta &= 6200 \text{ cm.}^{-1} \\ M_0 &= 6.0 \text{ cm.}^{-1} \end{aligned}$$

We calculate the level intervals using the above values. Thus the extrapolated level intervals are

$$^3P_2 - ^3P_1 = 5380 \text{ cm.}^{-1}$$

$$^3P_1 - ^3P_0 = 3750 \text{ cm.}^{-1}$$

In another paper, in preparation, I have shown for a number of isoelectronic sequences that the level intervals fit remarkably well with a fourth degree polynomial. When a similar fit was carried out for the CI sequences, including PX, the results were entirely hopeless as is shown in Table II. No other polynomial of

TABLE II.

	$[^3P_1 - ^3P_0]_{\text{obs.}}$	$[^3P_1 - ^3P_0]_{\text{calc.}}$	$\Delta(\text{Obs.} - \text{Calc.})$	$[^3P_2 - ^3P_1]_{\text{obs.}}$	$[^3P_2 - ^3P_1]_{\text{calc.}}$	$\Delta(\text{Obs.} - \text{Calc.})$
CI	16.4	4.4	12.0	27.1	20.6	6.5
NII	49.1	73.0	-23.9	82.2	95.2	-13.0
OIII	113.4	119.5	-6.1	193.4	196.6	-3.2
FIV	225.2	206.0	19.2	388.2	378.4	9.8
NeV	414	389.9	24.1	698	686.6	11.4
NaVI	698	699.3	-1.3	1160	1159.7	0.3
MgVII	1127	1157.3	-30.3	1812	1828.5	-16.5
AlVIII	1740	1770.1	-30.1	2700	2716.0	-16.0
SiIX	2590	2529.4	60.6	3870	3837.7	32.3
PX	3390	3411.9	-21.9	5190	5201.6	-11.6

a reasonable degree would be able to represent the energy levels of all ten atoms of the CI sequence. However, when PX was omitted I was able to get an extremely close fit with a fourth degree polynomial as is shown in Table III.

TABLE III.

	$[^3P_1 - ^3P_0]_{\text{calc.}}$	$\Delta(\text{Obs.} - \text{Calc.})$	$[^3P_2 - ^3P_1]_{\text{calc.}}$	$\Delta(\text{Obs.} - \text{Calc.})$
CI	16.5	-0.1	27.1	0
NII	48.7	0.4	82.3	-0.1
OIII	113.4	0	193.4	0
FIV	226.6	-1.4	388.1	0.1
NeV	411.8	2.2	698.2	-0.2
NaVI	699.3	-1.3	1159.7	0.3
MgVII	1126.9	0.1	1812.3	-0.3
AlVIII	1739.8	0.2	2699.8	0.2
SiIX	2590.0	0	3870.0	0

From the empirical formula for the first nine members of the sequence, we can extrapolate the intervals for PX. In this way we obtain

$$^3P_2 - ^3P_1 = 5375 \text{ cm.}^{-1}$$

$$^3P_1 - ^3P_0 = 3740 \text{ cm.}^{-1}$$

These values are in good agreement with those obtained above from the extrapolated values of ζ and M_0 . These extrapolated values are, perhaps, more accurate than Robinson's spectroscopic results.

It should be remarked here that the value of M_0 calculated empirically according to our procedure appears to be very sensitive to errors in the observed positions of the energy levels.

There is much uncertainty in the positions of the 1S_0 and 1D_2 levels of several atoms of the CI sequence because no intersystem lines connecting the singlet and the triplet systems have been observed. Similar extrapolations for 1S_0 and 1D_2 levels of PX, therefore, do not seem worth while. A brief examination reveals no large discrepancy in Robinson's values of these two energy levels.

SUMMARY.

H. A. Robinson's values for the energies of the three 3P levels of the ground configuration of PX appear to be in error. They have therefore been calculated by two different methods of extrapolation along the isoelectronic sequence, which give results in good agreement with one another.

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Moore, Charlotte E. (1949). Atomic Energy Levels, Vol. I, Circular No. 467, National Bureau of Standards, Washington, D.C.

NOTE.

Since this paper was written the author has received the second volume of the Atomic Energy Levels in which Miss Moore writes (in the section on Additions and Corrections to volume I), 'H. A. Robinson in private conversation has stated that the terms having the configuration $2s2p^3$ (of PX) need revision'. This statement as well as the results given above indicate that perhaps the entire analysis for PX may require revisions. There are also indications that the analysis for P IX and possibly for other stages of ionization of phosphorus should also be repeated. However, since Robinson's work on the analysis of the spectra of phosphorus for the ionization stages above the fifth is still unpublished, and also no other experimental data are available, it is not possible to remove the discrepancy. Further theoretical investigation for this atom is in progress.

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A THEOREM ON MATRICES ANALOGOUS TO FERMAT'S THEOREM

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In this note I prove the following theorem :—

THEOREM :—Let p be an arbitrary prime, α any arbitrary positive integer, I the unit matrix of order n , B a square matrix of order n such that $B^2 \equiv I \pmod{2p}$, then¹

$$B^{2p^{\alpha-1}} \equiv I \pmod{2p^{\alpha}}.$$

*Proof :—*Since $B^2 \equiv I \pmod{2p}$, the theorem holds for $\alpha = 1$. We assume that the theorem holds for $\alpha = k$ and show that it must hold for $\alpha = k+1$.

*Case 1 :—*Let $p = 2$. Consider the identity

$$\begin{aligned} (B^{2^k} - I)^2 &= B^{2^{k+1}} - 2B^{2^k} + I \\ &= B^{2^{k+1}} - I - 2(B^{2^k} - I). \end{aligned}$$

Now $B^{2^k} - I \equiv o \pmod{2^{k+1}} \dots$ (by inductive assumption).

So $2(B^{2^k} - I) \equiv o \pmod{2^{k+2}}.$

Therefore we have $(B^{2^k} - I)^2 \equiv B^{2^{k+1}} - I \pmod{2^{k+2}}.$

But $(B^{2^k} - I)^2 \equiv o \pmod{2^{2(k+1)}} \equiv o \pmod{2^{k+2}}.$

Hence we have $B^{2^{k+1}} - I \equiv o \pmod{2^{k+2}}.$

*Case 2 :—*Now let p be any odd prime. Consider the identity

$$\begin{aligned} (B^{2p^{k-1}} - I)^p &= B^{2p^k} - pB^{2(p-1)p^{k-1}} + \frac{p(p-1)}{1.2} B^{2(p-2)p^{k-1}} - \dots \\ &\quad - \frac{p(p-1)}{1.2} B^{2 \cdot p^{k-1}} + pB^{2p^{k-1}} - I. \end{aligned}$$

Since p is an odd number, the binomial coefficients occur in pairs which are equal in absolute value but opposite in sign. We write the identity as follows :

$$\begin{aligned} (B^{2p^{k-1}} - I)^p &= (B^{2p^k} - I) - p(B^{2(p-1)p^{k-1}} - I) + \frac{p(p-1)}{1.2} (B^{2(p-2)p^{k-1}} - I) - \dots \\ &\quad - \frac{p(p-1)}{1.2} (B^{2 \cdot p^{k-1}} - I) + p(B^{2p^{k-1}} - I). \end{aligned}$$

¹ For a similar result see Davis (1951).

The coefficients on the right-hand side of the identity are all, except for the first, multiples of p . Also since for all positive integral values of x , $B^{2xp^{k-1}} - I$ is a multiple of $B^{2p^{k-1}} - I$, we have

$$B^{2xp^{k-1}} - I \equiv o(\text{mod } 2p^k) \text{ because } B^{2p^{k-1}} - I \equiv o(\text{mod } 2p^k) \quad (\text{by inductive assumption}).$$

$$\text{Therefore} \quad (B^{2p^{k-1}} - I)^p \equiv B^{2p^k} - I (\text{mod } 2p^{k+1}).$$

$$\text{But} \quad (B^{2p^{k-1}} - I)^p \equiv o(\text{mod } 2^p \cdot p^k) \equiv o(\text{mod } 2p^{k+1}).$$

$$\text{Therefore} \quad B^{2p^k} - I \equiv o(\text{mod } 2p^{k+1}).$$

This completes the proof of the theorem.

COROLLARY :—Let A be a square matrix of order n such that $A \equiv I (\text{mod } 2p)$ and α be any arbitrary positive integer, then

$$A^{p^{\alpha-1}} \equiv I (\text{mod } 2p^\alpha).$$

§ 2. We give three examples.

Example No. 1 : Let $p = 5$, $\alpha = 2$, $n = 3$ and

$$B^2 = \begin{bmatrix} 1 & 0 & 20 \\ 20 & 11 & 0 \\ 0 & 10 & 21 \end{bmatrix} \equiv I (\text{mod } 10).$$

Then

$$B^{10} = \begin{bmatrix} 3440001 & 4562000 & 8484100 \\ 3922100 & 5401051 & 9124000 \\ 4562000 & 6523050 & 11924101 \end{bmatrix} \equiv I (\text{mod } 50) \text{ or } (\text{mod } 2p^\alpha).$$

Example No. 2 : Let $n = 4$, $p = 3$, $\alpha = 2$ and

$$B^2 = \begin{bmatrix} 7 & 0 & 0 & 6 \\ 0 & 13 & 0 & 12 \\ 12 & 0 & 7 & 0 \\ 0 & 6 & 0 & 13 \end{bmatrix} \equiv I (\text{mod } 2p).$$

Then

$$B^6 = \begin{bmatrix} 343 & 1188 & 0 & 2286 \\ 0 & 5005 & 0 & 6948 \\ 1764 & 432 & 343 & 1944 \\ 0 & 3474 & 0 & 5005 \end{bmatrix} \equiv I (\text{mod } 18).$$

Example No. 3 : Let $n = 3$, $p = 3$, $\alpha = 2$ and

$$B^2 = \begin{bmatrix} 1 & 36 & 84 \\ 96 & 49 & 72 \\ 72 & 120 & 169 \end{bmatrix} \equiv I (\text{mod } 6).$$

Then we may take

$$B = \begin{bmatrix} 1 & 0 & 6 \\ 12 & 7 & 0 \\ 0 & 6 & 13 \end{bmatrix} \equiv I \pmod{6}.$$

And

$$B^6 = \begin{bmatrix} 236479 & 2948940 & 4505148 \\ 3112416 & 3920977 & 5897880 \\ 589788 & 7454088 & 11375065 \end{bmatrix} \equiv I \pmod{18}.$$

Finally I wish to acknowledge with thanks a scholarship granted to me by the U.P. Government. I must also thank Dr. S. M. Shah for suggesting the problem and for helpful criticisms.

SUMMARY.

In this note I prove a theorem and a corollary with three examples similar to a result of A. S. Davis on matrices.

REFERENCE.

Davis, A. S. (1951). The Euler-Fermat's Theorem for Matrices. *Duke Math. Journal*, 18, 613-617.

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MORPHOLOGICAL STUDIES IN THE EUPHORBIACEAE

II. *MALLOTUS PHILIPPENSIS* M. ARG.

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(Communicated by P. Maheshwari, F.N.I.)

(Received August 28, 1952; read March 6, 1953.)

INTRODUCTION.

Previous investigations on the embryology of the Euphorbiaceae indicate that in the majority of plants, the development of the embryo sac is of the Polygonum type (Schnarf, 1931; Schürhoff, 1926). In a few genera tetrasporic embryo sacs have been reported. The Penaea type is found in *Euphorbia procera* and *E. palustris* (Modilewski, 1909, 1911), *Acalypha* species (Arnoldi, 1912), *A. australis* (Tateishi, 1927), *A. tricolor* (Swamy and Balakrishna, 1946), *A. rhomboidea* (Landes, 1946). *A. indica* (Maheshwari and Johri, 1941) shows a variation from the Penaea type in that the peripheral groups commonly consist of two cells, each with the remaining eight nuclei meeting at the centre. Banerji (1949) describes a similar condition in *A. fallax*. *A. lanceolata* (Thathachar, 1952) exhibits a *Peperomia hispida* (Johnson, 1914) type of embryo sac with a single synergid and an egg at the micropylar end while fourteen free nuclei fuse at the centre, without any trace of antipodals. Ventura (1934) observed the Drusa type of embryo sac in *Mallotus japonicus* and a similar condition is noticed in *Mallotus albus* by Raju and Nagaraja Rao (1952). The present work deals with the development of male and female gametophytes and embryo in *Mallotus philippensis*, a plant which is of some economic importance since the pigmented glandular outgrowths of its fruits form the source of the 'Kamala' dye. Nawaschin's fixative with prefixation in Carnoy's fluid gave satisfactory results. The material was collected and sectioned for microscopic study in the usual manner.

ANTHER AND POLLEN.

The young anther is slightly four-lobed in cross-section. The innermost wall layer forms the tapetum which is of the glandular type. The nuclei of the enlarging tapetal cells divide mitotically. The binucleate condition of the tapetal cell is the most common but further divisions and fusions of the tapetal nuclei have also been observed. A similar behaviour of the tapetal nuclei has been recorded in *Putranjiva roxburghii* by Dutt (1942). Quadripartition of the microspore mother cells takes place by peripheral furrows as in other members of the Euphorbiaceae. The mature pollen grain is two-celled (Fig. 1) and has three furrows with a median germ pore in each. Ventura (1934) figures the mature pollen grain of *M. japonicus* as uninucleate, but this is probably incorrect (see comments by Maheshwari, 1949). The endothecium is fibrous and a distinct stomium is organized.

THE OVULE.

In each of the three locules of the tricarpeillary ovary an anatropous ovule is found attached to the upper end of the placenta (Fig. 2). The nucellar primordium is massive with a slightly tapering apex. The outer integument soon outgrows the inner which it envelops completely. It develops to a greater extent on the

free side of the ovule than on its proximal side and by further growth produces a zigzag micropyle (Fig. 4) as in *Mallotus japonicus* (Ventura, 1934). The parenchymatous obturator arises above the funiculus on the placenta.

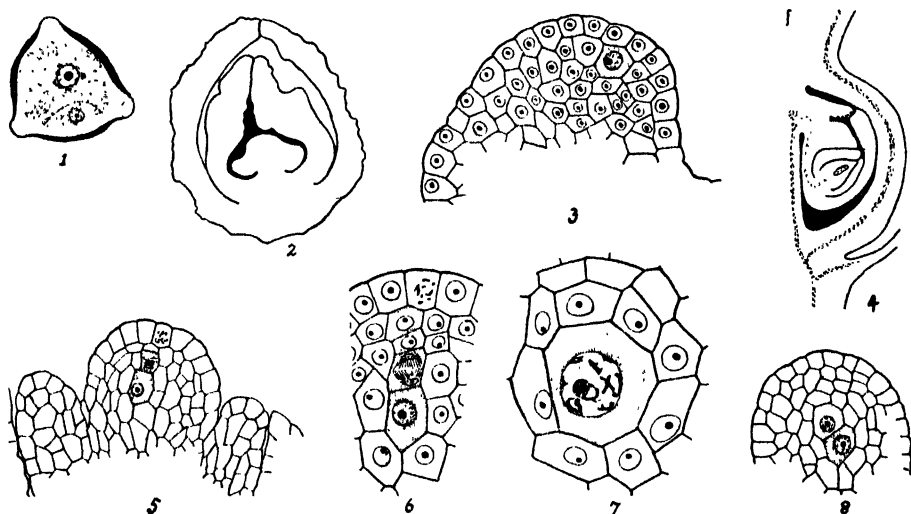


FIG. 1. Two-celled pollen grain. $\times 900$.
 „ 2. Long section of pistillate flower. $\times 37$.
 „ 3. Tip of the nucellus showing the primary archesporial cell. $\times 420$.
 „ 4. Long section of ovary showing the ovules and the obturator. $\times 50$.
 „ 5. Megaspore mother cell with parietal cells above it. $\times 300$.
 „ 6. Same as above enlarged to show one of the parietal cells in division. Anticlinal division in an epidermal cell is also seen. $\times 600$.
 „ 7. Nucleus of the megaspore mother cell in diakinesis. $\times 400$.
 „ 8. Double megaspore mother cells in the same nucellus. $\times 275$.

FEMALE GAMETOPHYTE.

The primary archesporial cell is hypodermal in origin (Fig. 3). Several instances of multiple megaspore mother cells were also noticed (Fig. 8). The parietal cell cut off by the archesporial cell undergoes anticlinal and periclinal divisions which cause the megaspore mother cell to become deep-seated (Figs. 5, 6).

The nucleus of the megaspore mother cell enters the meiotic prophase (Fig. 7). The two daughter nuclei are not separated by a wall (Figs. 9, 10), and divide again after a brief interphase resulting in four nuclei. The orientation of the two spindles is variable (Figs. 11, 12). The four daughter nuclei are arranged at first in a linear manner in the elongated embryo sac (Fig. 12). No prominent vacuoles are seen up to this stage. By gradual enlargement the embryo sac assumes an oval contour and several small vacuoles soon make their appearance around the nuclei. These finally fuse in the middle of the embryo sac, pushing the cytoplasm with its four nuclei to a peripheral position. At this stage the nuclei usually show a cruciform arrangement (Fig. 13). Ventura (1934) noted a 1+3 arrangement of these nuclei in *Mallotus japonicus*, but such a tendency was not seen in *M. philippensis*.

With the rapid increase in size of the embryo sac, the parietal layer of cytoplasm becomes thinner. The four megaspore nuclei divide in their respective positions (Fig. 14) and give rise to four pairs of nuclei (Fig. 15). By one more division of these nuclei sixteen nuclei are formed in four quartets—one quartet each at the micropylar and chalazal ends, the remaining two being lateral in position (Fig. 16). In *M. japonicus* (Ventura, 1934) there is only a micropylar quartet while the remaining twelve nuclei are found at the chalazal end.

In each of the four quartets in the embryo sac, three nuclei become surrounded by delicate walls, leaving one free nucleus in each group (Fig. 17). These four free nuclei move towards the middle of the embryo sac where they coalesce to form a tetraploid fusion nucleus (Fig. 18). In *Mallotus japonicus* (Ventura, 1934) the organization of the embryo sac is bipolar from the four nucleate stage onwards: the secondary nucleus is diploid, being formed by the micropylar polar nucleus and one out of the twelve nuclei at the chalazal end. The development in *M. philippensis* resembles that of *Euphorbia procera* and *E. palustris* (Modilewski, 1909, 1911) and all of these conform to the Penaea type (Stephens, 1909). In *M. japonicus* (Ventura, 1934) and *M. albus* (Raju and Nagaraja Rao, 1952), it is of the Drusa type (Hakanesson, 1922).

In the mature embryo sac the pyriform synergids are beaked and show a filiform apparatus. The egg is usually located between them. The three cells of each of the lateral groups are quite conspicuous and egg-like in appearance with their nuclei placed towards the base (Fig. 18). Prior to fertilization a small globular darkly stained body is found close to the nucleus in these cells. The exact nature of this substance and its significance have not been determined. The two lateral triads often persist till the early stages of endosperm development.

In one instance a problematic seven-nucleate embryo sac was noticed in one ovule while the other two ovules of the same ovary showed the presence of sixteen nucleate embryo sacs of the Penaea type (Fig. 19). The synergids and egg are rather elongated. The three antipodal cells are large and there is a single free nucleus in the centre of the embryo sac, probably the diploid secondary nucleus. This embryo sac may be interpreted as a normal monosporic eight-nucleate embryo sac becoming seven nucleate at maturity or as an eight-nucleate embryo sac of tetrasporic origin. The latter appears to be more likely because during the course of this work there was not a single instance of normal megaspore formation with walls separating them. There is also no indication of a linear or a T-shaped tetrad or the degeneration of any of the megaspores as is usually noticed in a monosporic course of development.

The pollen tube travels in the intercellular spaces of the tissue of the obturator and the nucellar beak. There is a swelling of the walls of the obturator and the nucellar beak and a slight cleavage is developed amidst the cells when the pollen tube passes between them. The egg nucleus is in a resting condition at the time of fertilization. The four polar nuclei fuse by now to form a conspicuous secondary nucleus (Figs. 18, 20), which after fertilization forms a pentaploid primary endosperm nucleus. The lateral triads persist up to this stage while the antipodals may or may not do so.

ENDOSPERM.

The primary endosperm nucleus divides earlier than the zygote and the daughter nuclei migrate to the opposite ends of the elongating embryo sac. By further divisions free nuclei are formed and become uniformly distributed in the parietal layer of cytoplasm (Figs. 21-23). Eventually the endosperm becomes cellular throughout.

EMBRYO.

The zygote in *Mallotus philippensis* divides at about the four-nucleate or the eight-nucleate stage of endosperm (Figs. 21, 22). Its first division is transverse or slightly oblique (Figs. 24, 25), forming the primary embryonal and suspensor cells. The embryonal cell next divides vertically (Fig. 25). Transverse divisions of the primary suspensor cells result in a row of three or four cells (Figs. 26, 27). The vertical division that is first seen in the primary embryonal cell extends to the cells of the suspensor above it, the basal cell also finally undergoing a longitudinal division (Figs. 27, 28). Thus the distinction between the suspensor and embryonal regions disappears (Fig. 29). Another series of longitudinal divisions, commencing

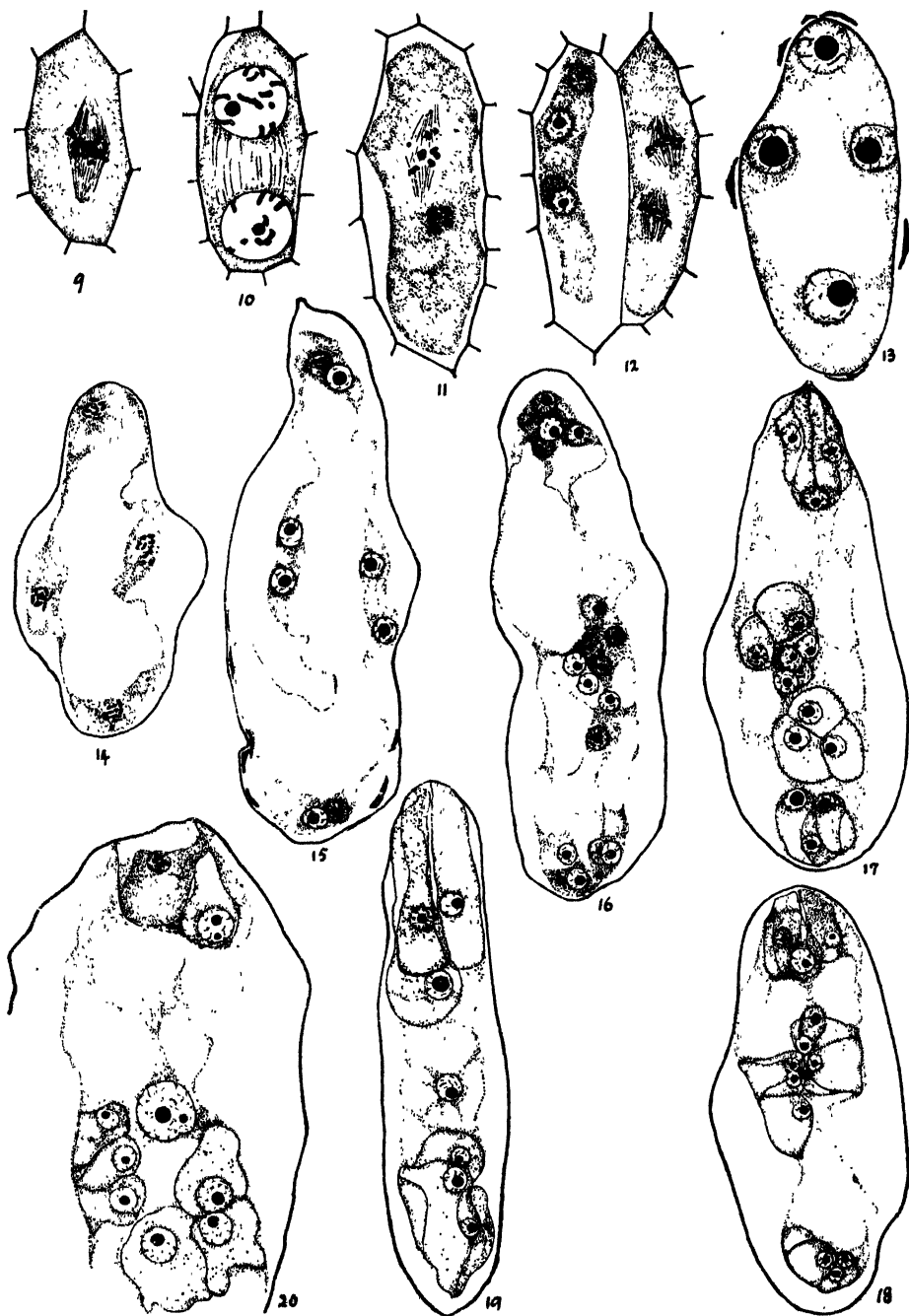
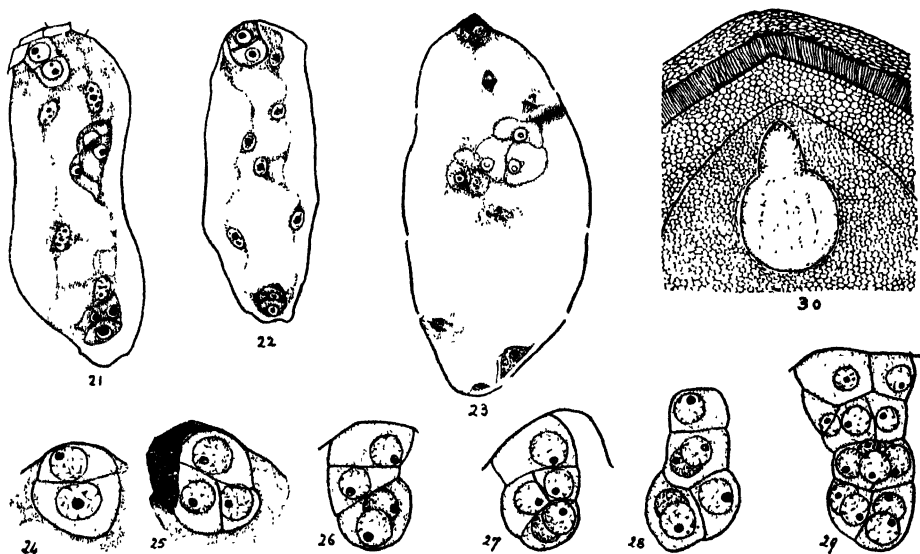


FIG. 9. First division of the nucleus in the megaspore mother cell. $\times 900$.
 „ 10. Late telophase of the first division in the megaspore mother cell. No wall is formed between the daughter nuclei. $\times 900$.
 „ 11. Division of the two nuclei in the embryo sac. $\times 900$.
 „ 12. Double embryo sacs in the same ovule. One is four-nucleate and in the other the two nuclei are dividing. $\times 900$.

(Continued at foot of next page.)

from the terminal tiers and at right angles to the previous plane of division, ultimately gives rise to three or four tiers of four cells each (Fig. 29). Subsequent divisions are not so regular.



FIGS. 21-23. Stages in the development of endosperm. Fig. 21: $\times 225$. Fig. 22: $\times 200$.
Fig. 23: $\times 270$.
" 24-29. Stages in the development of embryo. $\times 425$.
Fig. 30. Late embryo surrounded by the endosperm cells. $\times 15$.

The fully differentiated embryo is completely surrounded by the endosperm tissue and has two flattened cotyledons enclosing the stem tip (Fig. 30). As in other plants of the Euphorbiaceae, the root tip is invested by a well-developed root cap.

Ventura (1934) noticed the presence of two embryos in *Mallotus japonicus*. Though similar indications were seen in several preparations of *Mallotus philippensis*, these were not sufficiently clear to conclude that polyembryony occurs in the present species.

CONCLUSION.

The foregoing description makes it clear that the embryo sac of *Mallotus philippensis* is of the Penaea type, as in a few species of *Euphorbia* and a number of species of *Acalypha* (Maheshwari, 1950). This differs from the other two species—*Mallotus japonicus* (Ventura, 1934) and *M. albus* (Raju and Nagaraja Rao, 1952)—where a Drusa type of embryo sac is seen. In these the primary endosperm nucleus would be triploid while in *M. philippensis* it is pentaploid. The occurrence of an

(Continued from previous page.)

- FIG. 13. Four-nucleate embryo sac with a large central vacuole. $\times 970$.
" 14. Division of the four nuclei in the embryo sac. $\times 600$.
" 15. Eight-nucleate embryo sac. $\times 600$.
" 16. Sixteen-nucleate embryo sac. $\times 600$.
" 17. Embryo sac showing the formation of four triads of cells with four free nuclei meeting in the middle. $\times 425$.
" 18. Mature embryo sac with the egg apparatus, lateral triads and the antipodals. The four polar nuclei have fused into a single secondary nucleus. $\times 425$.
" 19. Seven-nucleate embryo sac. $\times 425$.
" 20. Double fertilization. $\times 600$.

exceptional eight-nucleate embryo sac in this plant is noteworthy. While no definite conclusions are possible, this is suggestive of the derivation of the Adoxa type of embryo sac from the Penaea type by the omission of the last division and the consequent elimination of the lateral quartets. It is possible that polyembryony occurs in *M. philippensis* as in the other species, but further work is necessary for a definite conclusion on this point. The development of the embryo is characterized by the shortness of the suspensor, its multiseriate condition and by the lack of a distinct demarcation between the suspensor and the embryo into which the former merges.

SUMMARY.

The anther tapetum is of the secretory type with its cells containing two or more nuclei. Fusion of these nuclei leads to their polyploid condition. The mature pollen grain is binucleate.

The anatropous ovule with a massive nucellus is invested by two integuments of which the outer develops to a greater extent.

The occurrence of multiple megaspore mother cells is a common feature.

The tetrasporic embryo sac conforms to the Penaea type unlike those of *Mallotus japonicus* and *M. albus* which correspond to the Drusa type.

The endosperm is free nuclear and later becomes cellular throughout.

The embryo has a short and multiseriate suspensor which merges into the embryo in the later stages.

ACKNOWLEDGEMENTS.

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ON A TYPE OF VECTOR SPACE

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In recent years H. S. Ruse and A. G. Walker have developed in a number of papers a theory of parallel fields of vector spaces in an n -dimensional Riemannian manifold. The theory is concerned with the properties of subspaces of the n -dimensional vector space at a point of the manifold and of their parallel displacements to a neighbouring point and with the nature of manifolds admitting different kinds of parallel subspaces. The object of this paper is to find an abstract algebraic system which could reproduce some of these properties. Of course, the literature on the algebraic theory of vector spaces is quite extensive; but the main problem here is to postulate a suitable set of axioms which would serve the purpose mentioned above. It would be convenient to describe the system gradually.

1. PRELIMINARY NOTIONS.

The following fundamentals on the abstract theory of vector spaces given in this section is well known (Levi, 1942).

Let \mathcal{A} be an additive Abelian group having its singular element denoted by O and other elements by Greek letters, and F be a field having its zero and unit elements denoted by 0 and 1 and other elements by Roman letters. Let us suppose that they satisfy the following two kinds of axioms:—

I. There exists a multiplication by which every element of \mathcal{A} can be multiplied with every element of F such that the product belongs to \mathcal{A} and satisfies the following properties:—

- (i) $1\lambda = \lambda$,
- (ii) $a\lambda = \lambda a$,
- (iii) $a(b\lambda) = (ab)\lambda$,
- (iv) $(a+b)\lambda = a\lambda + b\lambda$, $a(\lambda + \mu) = a\lambda + a\mu$.

II. There exist a finite number of n elements $\alpha_1, \dots, \alpha_n$, say, of \mathcal{A} , such that every element of α of \mathcal{A} can be expressed as

$$\alpha = a_1\alpha_1 + \dots + a_n\alpha_n$$

by suitable choice of the elements a_1, \dots, a_n of F and that

$$a_1\alpha_1 + \dots + a_n\alpha_n = O \text{ implies } a_1 = \dots = a_n = 0.$$

Under the above suppositions, \mathcal{A} is called a *vector space*, denoted by V_n , say, over F and the elements of V_n are called *vectors*. The set $\alpha_1, \dots, \alpha_n$ is called a *basis* and n the *dimension* of V_n .

Definitions.—Given a set Γ of vectors $\lambda_1, \dots, \lambda_m$ of V_n : The set Γ is said to be an *independent set* if

$$\sum_{i=1}^m a_i \lambda_i = O$$

implies $a_1 = \dots = a_m = 0$; otherwise Γ is a *dependent* set. The set of all vectors $\sum a_i \lambda_i$ of V_n , as a_1, \dots, a_m run over the element of F , is a vector space V , say; and if Γ is an independent set, V has Γ as a basis and is of dimension m . A vector space V is a subspace of a vector space W if every vector of V is a vector of W .

It follows that the number of vectors in any independent set of V_n is less than or equal to n and that every vector space is a subspace of V_n . The vector space V_0 , say, consisting of the vector O only has no basis and it is a subspace of every vector space; its dimension may be regarded as 0. Every vector space, other than V_0 , has more than one basis but has a unique dimension. As a matter of fact, if $\lambda_1, \dots, \lambda_r$ is a basis of a vector space V and

$$\mu_i = \sum_{k=1}^r a_{ik} \lambda_k, \quad i = 1, \dots, r,$$

then μ_1, \dots, μ_r is a basis of V if and only if the rank of the matrix of the coefficients a_{ik} is equal to r . Lastly, the sum and intersection of vector spaces are vector spaces.

2. ORTHOGONALITY.

Let us now suppose that the vector space V_n described in the last section possesses the following properties:—

The group A is of infinite order and the field F is of characteristic zero. Moreover, there exists a multiplication for every pair of vectors λ, μ of V_n such that the product $\lambda\mu$ belongs to F and satisfies the following five axioms:—

1. $\lambda\mu = \mu\lambda$.
2. $a(\lambda\mu) = (a\lambda)\mu$.
3. $\lambda(\mu + \nu) = \lambda\mu + \lambda\nu$.
4. V_n contains at least one vector λ such that $\lambda\lambda \neq 0$ and at least one vector $\lambda \neq O$ such that $\lambda\lambda = 0$.
5. There exists no vector $\lambda \neq O$ of V_n such that $\lambda\mu = 0$ for all vectors μ of V_n .

Definitions.—If $\lambda\mu = 0$, λ and μ are called *orthogonal* vectors. If $\lambda\lambda = 0$, λ is called a *null* vector. A vector space which consists of null vectors only is called a *null* space. A basis of a vector space which consists of mutually orthogonal vectors is called an *orthogonal* basis. Two vector spaces are called *orthogonal* if every vector of one is orthogonal to every vector of the other. Two orthogonal vector spaces having dimensions r and $n-r$ are called *conjugate*.

Notations.—Let $[a_{ij}]$ and $[\lambda_1 \dots \lambda_r]$ denote respectively the $r \times s$ matrix and the $r \times r$ symmetric matrix

$$\begin{bmatrix} a_{11} & \dots & a_{1s} \\ \vdots & \ddots & \vdots \\ a_{r1} & \dots & a_{rs} \end{bmatrix} \text{ and } \begin{bmatrix} \lambda_1 \lambda_1 & \dots & \lambda_1 \lambda_r \\ \vdots & \ddots & \vdots \\ \lambda_r \lambda_1 & \dots & \lambda_r \lambda_r \end{bmatrix}.$$

Also, let I_s denote the $s \times s$ unit matrix and M^T denote the transposed of any matrix M .

The following properties now follow from the above assumptions and definitions.

Theorem 1.—Any basis of a null space is a set of independent orthogonal null vectors, and conversely.

Proof.—If $\lambda_1, \dots, \lambda_r$ are any r vectors of a null space, then the rank of $[\lambda_1 \dots \lambda_r]$ is 0. For, let

$$\alpha = \sum_{k=1}^r a_k \lambda_k; \text{ then } 0 = \alpha\alpha = \sum_{i,k=1}^r a_i a_k \lambda_i \lambda_k.$$

As this holds for arbitrary a_1, \dots, a_r , so $\lambda_i \lambda_k = 0$. A null space is therefore self-orthogonal and so is its basis. Conversely, if $\lambda_1, \dots, \lambda_r$ are orthogonal null vectors, then $\alpha\alpha = 0$; so $\lambda_1, \dots, \lambda_r$ is a basis of a null space if they are independent.

Theorem 2.—Any orthogonal basis of V_n is a set of n orthogonal non-null vectors, and conversely.

Proof.—If the set $\lambda_1, \dots, \lambda_n$ is a basis of V_n , then the rank of $[\lambda_1 \dots \lambda_n]$ is n . For, let

$$\alpha = \sum_{j=1}^n x_j \lambda_j.$$

Consider the following equations

$$(\lambda_1 \lambda_1) x_1 + \dots + (\lambda_1 \lambda_n) x_n = 0,$$

$$\dots \dots \dots$$

$$(\lambda_n \lambda_1) x_1 + \dots + (\lambda_n \lambda_n) x_n = 0.$$

By axiom 4, V_n is not a null space and therefore, by the above theorem, $\lambda_i \lambda_j$ are not all zero, i.e., the above equations are not identically satisfied. These equations may be written as

$$\lambda_1 \alpha = 0, \dots, \lambda_n \alpha = 0.$$

They are satisfied either by $\alpha = 0$ or by $\alpha \neq 0$ orthogonal to $\lambda_1, \dots, \lambda_n$ and therefore, as the λ 's form a basis, $\alpha \neq 0$ is orthogonal to every vector of V_n . As the second alternative is contrary to axiom 5, we must have $\alpha = 0$, i.e., $x_1 = \dots = x_n = 0$. Therefore the rank of $[\lambda_1 \dots \lambda_n]$ is n . If therefore the basis is an orthogonal set, i.e., if $[\lambda_1 \dots \lambda_n]$ is a diagonal matrix, then $\lambda_1, \dots, \lambda_n$ must be non-null. Conversely, it is easily seen that if $\lambda_1, \dots, \lambda_r$ is any orthogonal non-null set, it is independent.

Theorem 3.—A vector space of r dimensions, $1 < r \leq n$, has always an orthogonal basis.

Proof.—The following facts are known (Levi, 1942). An $r \times r$ elementary matrix $E_{st}(a)$, $s \neq t$, over a field is defined as follows:

$$\text{Let } E_{st}(a) = [e_{ik}].$$

Then $e_{ii} = 1$ ($i = 1, \dots, r$), $e_{st} = a$, $e_{ik} = 0$ for $i \neq k$ and $(i, k) \neq (s, t)$.

Multiplication of an $r \times r$ matrix M over the same field from the left by $E_{st}(a)$ means therefore a row addition in M by which the s -th row of M is replaced by the sum of the t -th row multiplied by a and the s -th row. Similarly, multiplying M from the right by $E_{st}(a)$, we get a column addition in M by which the t -th column of M is replaced by the sum of the s -th column multiplied by a and the t -th column. By successive multiplications with suitable elementary matrices from the left and the right, any matrix M can be transformed into a diagonal matrix.

Let now $\lambda_1, \dots, \lambda_r$ and $\alpha_1, \dots, \alpha_r$ be two sets of r vectors of a vector space V and

$$\alpha_i = \sum_{k=1}^r a_{ik} \lambda_k, \quad i = 1, \dots, r.$$

Then it can be directly seen that

$$[a_{ik}] [\lambda_1 \dots \lambda_r] [a_{ik}]^T = [\alpha_1 \dots \alpha_r]. \quad (2.1)$$

If moreover the two sets are bases of V , then the rank of the matrix $[a_{ik}]$ is equal to r .

From what has been said above regarding elementary matrices it follows that a finite number of suitable elementary matrices can be so chosen that

$$E_{pq}(b) \dots E_{st}(a) [\lambda_1 \dots \lambda_r] E_{st}^T(a) \dots E_{pq}^T(b)$$

is a diagonal matrix. That is to say, $[a_{ik}]$ can be so chosen as a product $E_{pq}(b) \dots E_{st}(a)$ of suitable elementary matrices that, by (2.1), the set $\alpha_1, \dots, \alpha_r$ becomes an orthogonal basis of V .

E.g., let $r = 2$. If one of the two vectors λ_1, λ_2 of the basis, say λ_1 , is non-null, we may choose

$$[a_{ik}] = \begin{bmatrix} 1 & 0 \\ -\frac{\lambda_1 \lambda_2}{\lambda_1 \lambda_1} & 1 \end{bmatrix}$$

And if both λ_1 and λ_2 are null vectors, we may have

$$[a_{ik}] = \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & 1 \end{bmatrix} \begin{bmatrix} 1 & 1 \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ -\frac{1}{2} & \frac{1}{2} \end{bmatrix}$$

Theorem 4.—Every orthogonal basis of a given vector space contains the same number of null vectors.

Proof.—As in the last theorem, let $\lambda_1, \dots, \lambda_r$ and $\alpha_1, \dots, \alpha_r$ be two bases of a vector space and $\alpha_i = \sum a_{ik} \lambda_k$. Then (2.1) holds, where $[a_{ik}]$ is of rank r . Therefore $[\lambda_1 \dots \lambda_r]$ and $[\alpha_1 \dots \alpha_r]$ have the same rank. The theorem now follows by supposing, by virtue of the last theorem, that both $[\lambda_1 \dots \lambda_r]$ and $[\alpha_1 \dots \alpha_r]$ are diagonal matrices.

Theorem 5.—Let an orthogonal basis of a given vector space V contain s null vectors and let these s null vectors generate a null space V' . Then V' consists of all those vectors of V which are orthogonal to every vector of V .

Proof.—Let $\lambda_1, \dots, \lambda_s, \lambda_{s+1}, \dots, \lambda_r$ be an orthogonal basis of V of which the first s vectors are null and the rest non-null, and let

$$\alpha = \sum_{k=1}^r a_k \lambda_k$$

be a vector of V which is orthogonal to every vector of V . It then follows from

$$\alpha \lambda_{s+1} = \dots = \alpha \lambda_r = 0$$

that

$$a_{s+1}(\lambda_{s+1} \lambda_{s+1}) = \dots = a_r(\lambda_r \lambda_r) = 0.$$

As $\lambda_{s+1}, \dots, \lambda_r$ are non-null vectors, $a_{s+1} = \dots = a_r = 0$.

Therefore $\alpha = a_1 \lambda_1 + \dots + a_s \lambda_s$ is a vector of V' .

Definition.—The vector space V' of the last theorem is called the *null part* of V and the number s is called the *nullity* of V .

Theorem 6.—Given a vector space V , its conjugate W consists of all those vectors of V_n which are orthogonal to every vector of V .

Proof.—Let $\lambda_1, \dots, \lambda_n$ be a basis of V_n and

$$\alpha_i = \sum_{j=1}^n a_{ij} \lambda_j, \quad i = 1, \dots, r$$

be a basis of V . Then the $r \times n$ matrix $[a_{ij}]$ has rank r . Also let

$$\beta = \sum_{j=1}^n x_j \lambda_j$$

be a vector of V_n which is orthogonal to every vector of V . Then we have the following system of r linear and homogeneous equations in the n unknowns x_1, \dots, x_n :—

$$\lambda_1(\Sigma a_{1j} \lambda_j) x_1 + \dots + \lambda_n(\Sigma a_{1j} \lambda_j) x_n = 0,$$

$$\lambda_1(\Sigma a_{rj} \lambda_j) x_1 + \dots + \lambda_n(\Sigma a_{rj} \lambda_j) x_n = 0.$$

The matrix of the coefficients of this system is the $r \times n$ matrix

$$M = \begin{bmatrix} \Sigma a_{1j} \lambda_1 \lambda_j & \dots & \Sigma a_{1j} \lambda_n \lambda_j \\ \dots & \dots & \dots \\ \Sigma a_{rj} \lambda_1 \lambda_j & \dots & \Sigma a_{rj} \lambda_n \lambda_j \end{bmatrix} = [a_{ij}] [\lambda_1 \dots \lambda_n].$$

As the rank of $[a_{ij}]$ is r and, by theorem 4, the rank of $[\lambda_1 \dots \lambda_n]$ is n , the rank of M is r (MacDuffee, 1943). Therefore the number of independent solutions of the above system is $n-r$, say $(x_1, \dots, x_n) = (b_{k1}, \dots, b_{kn})$, $k = 1, \dots, n-r$. These solutions give $n-r$ independent β 's, say $\beta_1, \dots, \beta_{n-r}$, which form a basis of W .

COROLLARY.—The conjugate of V_n is V_0 .

Theorem 7.—The intersection of two conjugate vector spaces is the null part of both.

Proof.—Let λ be a vector of the intersection of two conjugate vector spaces V and W . Then since λ is orthogonal to every vector of V , it belongs, by theorem 5, to the null part of V . Similarly, it belongs to the null part of W . On the other hand, if a vector μ belongs to the null part of V , it belongs to W , and conversely. Therefore μ belongs to the intersection of V and W .

COROLLARY.—If the null part of a vector space of r dimension has dimension s , then $s \leq \frac{1}{2}n$.

This follows from the last theorem owing to the fact that $s \leq$ the minimum of r and $n-r$.

3. NORMALITY.

Let the field F have the further property that every quadratic polynomial over F is reducible in $F[x]$ and let the roots of $x^2 + 1$ be denoted, as usual, by $\pm \sqrt{-1}$.

Definitions.—If $\lambda \lambda = 1$, λ is called a *unit vector*. An orthogonal basis in which the non-null vectors, if any, are unit vectors is called a *normal basis*.

Obviously, every orthogonal basis $\lambda_1, \dots, \lambda_r$ can be transformed into a normal basis. The matrix $[a_{ik}]$ of (2.1) corresponding to the transformation is a diagonal

matrix in which $a_{ii} = 1$ or $\frac{1}{\sqrt{\lambda_i \lambda_i}}$ according as λ_i is a null or a non-null vector.

A *quasi-normal* basis of V_n is a set of n independent vectors

$$\xi_1, \dots, \xi_r, \xi_{r+1}, \dots, \xi_{2r}, \xi_{2r+1}, \dots, \xi_n, \quad (3.1)$$

where $1 \leq r \leq \frac{1}{2}n$, having the following properties:—

(i) The two sets of vectors ξ_1, \dots, ξ_r and $\xi_{r+1}, \dots, \xi_{2r}$ are bases of two null spaces, (ii) $\xi_i \xi_{k+r} = \delta_{ik}$ (Kronecker delta), $i, k = 1, \dots, r$, (iii) ξ_{2r+1}, \dots, ξ_n is a set of orthogonal (if more than one) unit vectors, and (iv) the vector space generated by ξ_1, \dots, ξ_{2r} and that generated by ξ_{2r+1}, \dots, ξ_n are conjugate.

The set ξ_{2r+1}, \dots, ξ_n may be empty if n is even. A quasi-normal basis of V_n may be constructed as follows: Let $\epsilon_1, \dots, \epsilon_n$ be a normal basis, ξ_1, \dots, ξ_n be a quasi-normal basis of V_n as defined above and

$$\xi_i = \sum_{j=1}^n a_{ij} \epsilon_j, \quad i = 1, \dots, n.$$

Then $[a_{ij}]$ is of rank n and $[\epsilon_1, \dots, \epsilon_n] = I_n$. It therefore follows from (2.1) that

$$[a_{ij}] [a_{ij}]^T = [\xi_1 \dots \xi_n] = \begin{bmatrix} \cdot & I_r & \cdot \\ I_r & \cdot & \cdot \\ \cdot & \cdot & I_{n-2r} \end{bmatrix} \quad (3.2)$$

We have therefore to choose $[a_{ij}]$ such that (3.2) is satisfied. Let S_r be any $r \times r$ symmetric matrix of rank r over F . Then $[a_{ik}]$ may be chosen as the matrix

$$\begin{bmatrix} \frac{S_r}{\sqrt{2}} & \frac{\sqrt{-1}S_r}{\sqrt{2}} & \cdot \\ \frac{S_r^{-1}}{\sqrt{2}} & \frac{-\sqrt{-1}S_r^{-1}}{\sqrt{2}} & \cdot \\ \cdot & \cdot & I_{n-2r} \end{bmatrix} = [s_{ij}], \text{ say.} \quad (3.3)$$

In particular, we may choose $S_r = I_r$ in (3.3).

It may be noticed that the matrix on the right-hand side of (3.2) is of a special type, namely, that it is a symmetric matrix in each of whose rows and columns there is exactly one element 1 while the other elements are 0. Let this permutation matrix be written as

$$P = \begin{bmatrix} p_1^1 & \cdot & \cdot & \cdot & p_n^1 \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ p_1^n & \cdot & \cdot & \cdot & p_n^n \end{bmatrix},$$

where

$$p_{r+1}^1 = p_{r+2}^2 = \dots = p_{2r}^r = p_1^{r+1} = p_2^{r+2} = \dots = p_r^{2r} = p_{2r+1}^{2r+1} = \dots = p_n^n = 1$$

and other elements are all 0. This shows that the matrix P represents (and, without ambiguity, identifies) a particular kind of permutation of n elements, say of $1, \dots, n$, namely, the permutation

$$P = \begin{pmatrix} 1 & \cdot & \cdot & \cdot & r & r+1 & \cdot & \cdot & 2r & 2r+1 & \cdot & \cdot & n \\ r+1 & \cdot & \cdot & \cdot & 2r & 1 & \cdot & \cdot & r & 2r+1 & \cdot & \cdot & n \end{pmatrix} = \begin{pmatrix} k \\ t_k \end{pmatrix}, \text{ say,}$$

which is a product of the transpositions $(1, r+1)(2, r+2) \dots (r, 2r)$. Therefore, by (2.1) and (3.3), we may write the equation transforming a normal basis to a quasi-normal basis of V_n as

$$[S_{ij}] \begin{pmatrix} k \\ k \end{pmatrix} [s_{ij}]^T = \begin{pmatrix} k \\ t_k \end{pmatrix}.$$

4. INVARIANCE.

Let the vector space V_n described in the last three sections have the following further property. There exists a functional on V_n which is defined for every vector λ of V_n , and every vector α of V_n is regarded as an operator which can operate, in accordance with a given law, on the functional of every vector λ such that the result of the operation is a vector of V_n denoted by (α, λ) , say. The vectors (α, λ) are supposed to satisfy the following four axioms:—

1. $(\alpha, \lambda + \mu) = (\alpha, \lambda) + (\alpha, \mu)$.
2. $(a\alpha, \lambda) = a(\alpha, \lambda)$.
3. $(\alpha, a\lambda) = a(\alpha, \lambda) + b\lambda$,
where b depends on α and a (the functional and the law of operation being given), but is independent of λ .
4. If, in axiom 3, $a = \mu\nu$, then $b = \mu(\alpha, \nu) + \nu(\alpha, \mu)$.

The following are the consequences of the above axioms: It follows from axiom 1 that $(\alpha, O) = O$ [for, $(\alpha, \lambda) = (\alpha, \lambda) + (\alpha, O)$] and so $(\alpha, -\lambda) = -(\alpha, \lambda)$; and from axiom 2 it follows that $(O, \lambda) = O$. Also it follows from axiom 1 that if p is a positive integral element of F (i.e., $p = 1 + 1 + \dots$ to p terms), then $(\alpha, p\lambda) = p(\alpha, \lambda)$ and therefore $(\alpha, -p\lambda) = -p(\alpha, \lambda)$. Hence if $p, q \neq 0$ are any two integral elements of F ,

$$q \left(\alpha, \frac{1}{q} \lambda \right) = (\alpha, \lambda), \text{ or } \left(\alpha, \frac{1}{q} \lambda \right) = \frac{1}{q} (\alpha, \lambda).$$

Therefore

$$\left(\alpha, \frac{p}{q} \lambda \right) = \frac{p}{q} (\alpha, \lambda).$$

Accordingly, it follows from axioms 3 and 4 that if a belongs to the prime field of F , $b = 0$ and therefore

$$\mu(\alpha, \nu) + \nu(\alpha, \mu) = 0. \quad (4.1)$$

In particular, if $\mu = \nu$ is a null or a unit vector,

$$\mu(\alpha, \mu) = 0. \quad (4.1')$$

Definition.—A vector space V is said to be *invariant* for an operator α if (α, V) belongs to V , where (α, V) is the set of vectors (α, β) for all vectors β of V .

It follows, by hypothesis, that V_n is invariant for every operator and that every vector space is invariant for O .

Theorem 1.—The necessary and sufficient condition that a vector space V with a basis $\lambda_1, \dots, \lambda_r$ be invariant for α is that there exist r^2 elements $A_{\alpha ik}$, say, $i, k = 1, \dots, r$ of F such that

$$(\alpha, \lambda_i) = A_{\alpha i1} \lambda_1 + \dots + A_{\alpha ir} \lambda_r, \quad i = 1, \dots, r. \quad (4.2)$$

Proof.—The set of vectors constituting V is given by

$$\sum_1^r a_i \lambda_i.$$

Therefore the set of vectors constituting (α, V) is given (by axioms 1 and 3) by

$$(\alpha, \sum a_i \lambda_i) = \sum (\alpha, a_i \lambda_i) = \sum a_i (\alpha, \lambda_i) + \sum b_i \lambda_i.$$

Hence V is invariant for α if and only if the equations (4.2) hold.

Theorem 2.—A vector space V is invariant for α if and only if its conjugate W is invariant for α .

Proof.—Let $\lambda_1, \dots, \lambda_r$ and μ_1, \dots, μ_{n-r} be bases of V and W so that $\lambda_i \mu_j = 0$ ($i = 1, \dots, r; j = 1, \dots, n-r$). Therefore, by (4.1),

$$\lambda_i(\alpha, \mu_j) + \mu_j(\alpha, \lambda_i) = 0.$$

If V is invariant for α , (4.2) hold and therefore $\mu_j(\alpha, \lambda_i) = 0$ and so $\lambda_i(\alpha, \mu_j) = 0$. Accordingly (α, μ_j) belongs to W and so there exist elements $B_{\alpha j l}$ of F such that

$$(\alpha, \mu_j) = B_{\alpha j l} \mu_l + \dots + B_{\alpha j n-r} \mu_{n-r}, \quad j = 1, \dots, n-r.$$

Hence W is invariant for α . Conversely, if W is invariant for α , i.e., if the above equations hold, $\lambda_i(\alpha, \mu_j) = 0$ and so $\mu_j(\alpha, \lambda_i) = 0$. This shows that (α, λ_i) belong to V and therefore (4.2) hold and so V is invariant for α .

Theorem 3.—If a vector space is invariant for α , its null part is also invariant for α .

Proof.—This follows immediately from the last theorem and theorem 7, §2.

The equations (4.2) show that each of the vectors (α, λ_i) is a linear combination of the basis vectors λ_k and the suffix α in the coefficients $A_{\alpha i k}$ merely says that these coefficients depend on α . There will therefore be no harm if, in what follows, this suffix is suppressed and the coefficients $A_{\alpha i k}$ are written simply as a_{ik} .

Let $\lambda_1, \dots, \lambda_n$ be a basis of V_n . Since V_n is invariant, there exist a_{ij} for which we shall have identically

$$(\alpha, \lambda_i) = \sum_{j=1}^n a_{ij} \lambda_j, \quad i = 1, \dots, n.$$

Therefore we have identically

$$[a_{ij}] [\lambda_1 \dots \lambda_n] = \begin{bmatrix} (\alpha, \lambda_1) \lambda_1 & \dots & (\alpha, \lambda_1) \lambda_n \\ \dots & \dots & \dots \\ (\alpha, \lambda_n) \lambda_1 & \dots & (\alpha, \lambda_n) \lambda_n \end{bmatrix} \equiv [(\alpha, \lambda_i) \lambda_j], \text{ say.} \quad (4.3)$$

Now, first suppose that $\lambda_1, \dots, \lambda_n$ is a normal basis of V_n , say $\epsilon_1, \dots, \epsilon_n$. Then it follows from (4.1) and (4.3) that $[a_{ij}]$ is a skew-symmetric matrix with $a_{ij} = (\alpha, \epsilon_i) \epsilon_j$. Let V be the vector space generated by $\epsilon_1, \dots, \epsilon_r$, $r \leq n$, and W the vector space generated by $\epsilon_{r+1}, \dots, \epsilon_n$ ($W = V_0$ if $r = n$). Then

$$(\alpha, V) + (\alpha, W) = (\alpha, V + W) = (\alpha, V_n).$$

If n is even and the rank of $[a_{ij}]$ is n , then $(\alpha, \epsilon_1), \dots, (\alpha, \epsilon_n)$ is a basis of V_n and so $(\alpha, V_n) = V_n$. If moreover V is invariant for α , then it follows from above that $(\alpha, V) = V$, $(\alpha, W) = W$. If, however, n is odd and the co-factor of a diagonal element a_{jj} ($= 0$) in determinant $[a_{ij}]$ is not zero, then $(\alpha, \epsilon_1), \dots, (\alpha, \epsilon_{j-1}), \epsilon_j, (\alpha, \epsilon_{j+1}), \dots, (\alpha, \epsilon_n)$ is a basis of V_n .

Secondly, suppose that $\lambda_1, \dots, \lambda_n$ is a quasi-normal basis of V_n , say ξ_1, \dots, ξ_n , as in (3.1) and as defined in (4.3), let the notation be

$$[(\alpha, \xi_i) \xi_j] = \begin{bmatrix} C & B & E \\ H & D & F \\ K & L & G \end{bmatrix},$$

where B, C, D, H are $r \times r$ matrices; E, F are $r \times (n-2r)$ matrices; K, L are $(n-2r) \times r$ matrices and G is an $(n-2r) \times (n-2r)$ matrix. As $\xi_s \xi_t = 0$ for $s, t = 1, \dots, r$,

so, by (4.1), $\xi_s(\alpha, \xi_i) + \xi_i(\alpha, \xi_s) = 0$. Therefore C is a skew-symmetric matrix. Similarly D, G are skew-symmetric. In the same manner it can be seen that $H = -B^T, K = -E^T$ and $L = -F^T$. It therefore follows from (4.3) that

$$[a_{ij}] = \begin{bmatrix} C & B & E \\ -B^T & D & F \\ -E^T & -F^T & G \end{bmatrix} [\xi_1 \dots \xi_n]^{-1}.$$

Hence, by (3.2),

$$[a_{ij}] = \begin{bmatrix} B & C & E \\ D & -B^T & F \\ -F^T & -E^T & G \end{bmatrix}, \quad (4.4)$$

where, as said above, C, D, G are skew-symmetric matrices. All the results corresponding to those given by Ruse (Ruse, 1950) in this connection can now be obtained by following his method. As an illustration, one of his results is given below with the obvious restriction adopted in this section.

Let n be even and $r = \frac{1}{2}n$. Then (4.4) reduces to

$$[a_{ij}] = \begin{bmatrix} B & C \\ D & -B^T \end{bmatrix}. \quad (4.5)$$

Let $B = [b_{ik}]$ and let the null space V of dimension $\frac{n}{2} - 1$ and with basis $\xi_1, \dots, \xi_{\frac{n}{2}-1}$ be invariant for α . Then $b_{1\frac{n}{2}} = \dots = b_{\frac{n}{2}-1\frac{n}{2}} = 0$ and C is a zero matrix. Therefore the vector space W', W'' and W with bases $\xi_1, \dots, \xi_{\frac{n}{2}}; \xi_1, \dots, \xi_{\frac{n}{2}-1}, \xi_n$ and $\xi_1, \dots, \xi_{\frac{n}{2}}, \xi_n$ respectively are also invariant for α . Hence, for an arbitrary operator α , we have the following theorem:

Theorem 4.—If n is even and V_n admits the invariant null space V , it also admits the two invariant null spaces W' and W'' intersecting in V . These spaces are all contained in the invariant vector space W of nullity $\frac{n}{2} - 1$ conjugate to V .

5. PARALLELISM.

The assumptions made in §4 lead to the following calculations: From axioms 1 and 4 it follows that if $\mu_1\nu_1 + \dots + \mu_r\nu_r$ belongs to the prime field of F , then for every operator α of V_n we have

$$\mu_1(\alpha, \nu_1) + \nu_1(\alpha, \mu_1) + \dots + \mu_r(\alpha, \nu_r) + \nu_r(\alpha, \mu_r) = 0. \quad (5.1)$$

And from axioms 1, 2, 3 we get, for every pair of operators α, β ,

$$\begin{aligned} (\beta, (a\alpha, b\lambda)) &= (\beta, a(\alpha, b\lambda)) = a(\beta, (\alpha, b\lambda)) + c(\alpha, b\lambda) \\ &= a(\beta, b(\alpha, \lambda) + d\lambda) + bc(\alpha, \lambda) + cd\lambda \\ &= a(\beta, b(\alpha, \lambda)) + a(\beta, d\lambda) + bc(\alpha, \lambda) + cd\lambda \\ &= ab(\beta, (\alpha, \lambda)) + ae(\alpha, \lambda) + ad(\beta, \lambda) + af\lambda + bc(\alpha, \lambda) + cd\lambda \\ &= ab(\beta, (\alpha, \lambda)) + ad(\beta, \lambda) + (ae + bc)(\alpha, \lambda) + (af + cd)\lambda, \end{aligned}$$

where $c = 0$, $d = e = 0$ and $f = 0$ according as a , b and d belong to the prime field of F . Lastly from axiom 4 we get

$$(\beta, \mu\nu(\alpha, \lambda)) = \mu\nu(\beta, (\alpha, \lambda)) + \{\mu(\beta, \nu) + \nu(\beta, \mu)\}(\alpha, \lambda);$$

and

$$\begin{aligned} (\beta, (\alpha, (\mu\nu)\lambda)) &= \mu\nu(\beta, (\alpha, \lambda)) \\ &+ \{\mu(\alpha, \nu) + \nu(\alpha, \mu)\}(\beta, \lambda) + \{\mu(\beta, \nu) + \nu(\beta, \mu)\}(\alpha, \lambda) \\ &+ \{(\beta, \mu)(\alpha, \nu) + (\alpha, \mu)(\beta, \nu) + \mu(\beta, (\alpha, \nu)) + \nu(\beta, (\alpha, \mu))\}\lambda, \end{aligned}$$

where, if $\mu\nu$ belongs to the prime field of F , the coefficients of the terms other than the first (if $\mu\nu \neq 0$) on the right-hand sides of the two equations are zero.

Definition.—A vector space V is said to be *parallel* if V is invariant for every operator of V_n .

By hypothesis V_n is parallel; and all the theorems of §4 which hold for invariance hold also, when suitably modified, for parallelism.

We shall consider here a particular case to obtain the conditions for a parallel vector space. Let $n = 4$, $r = 2$ and, by (3.1), let $\xi_1, \xi_2, \xi_3, \xi_4$ be a quasi-normal basis of V_4 . By (4.5), let the matrices corresponding to the operations of α and β to the functionals of the vectors of the basis be respectively

$$[a_{ij}] = \begin{bmatrix} b_{11} & b_{12} & 0 & c_{12} \\ b_{21} & b_{22} & -c_{12} & 0 \\ 0 & d_{12} & -b_{11} & -b_{21} \\ -d_{12} & 0 & -b_{12} & -b_{22} \end{bmatrix} \text{ and } [a'_{ij}] = \begin{bmatrix} b'_{11} & b'_{12} & 0 & c'_{12} \\ b'_{21} & b'_{22} & -c'_{12} & 0 \\ 0 & d'_{12} & -b'_{11} & -b'_{21} \\ -d'_{12} & 0 & -b'_{12} & -b'_{22} \end{bmatrix}$$

Then

$$(\beta, (\alpha, \xi_1)) = (b_{11}b'_{11} + b_{12}b'_{21} - c_{12}d'_{12} + a'_{11})\xi_1$$

$$+ (b_{11}b'_{12} + b_{12}b'_{22} + a'_{21})\xi_2 - (b_{12}c'_{12} + c_{12}b'_{12})\xi_3 + (b_{11}c'_{12} - c_{12}b'_{22} + a'_{41})\xi_4,$$

where the a'_i 's are given by axiom 3, §4. Similarly for $(\beta, (\alpha, \xi_2))$, etc. So the matrix corresponding to the operations of α first and then β is

$$[a_{ij}][a'_{ij}] + \begin{bmatrix} a'_1 & a'_2 & 0 & a'_4 \\ b'_1 & b'_2 & b'_3 & 0 \\ 0 & c'_2 & c'_3 & c'_4 \\ d'_1 & 0 & d'_3 & d'_4 \end{bmatrix}$$

Let us now suppose that the 2-dimensional null space with basis ξ_1, ξ_2 is parallel. Then, for every pair of operators α, β , we must have

$$c_{12} = (\alpha, \xi_1)\xi_2 = 0 \text{ and } c'_{12} = (\beta, \xi_1)\xi_2 = 0. \quad (5.2)$$

$$\left. \begin{aligned} \text{Therefore, by (4.1), } a'_4 &= (\beta, (\alpha, \xi_1))\xi_2 + (\beta, \xi_1)(\alpha, \xi_2) = 0 \\ \text{Interchanging } \alpha, \beta, \quad a_4 &= (\alpha, (\beta, \xi_1))\xi_2 + (\alpha, \xi_1)(\beta, \xi_2) = 0 \end{aligned} \right\} \quad (5.3)$$

And therefore by successive applications of (5.1) to (5.3) with all operators γ, δ, \dots of V_4 we obtain a series of conditions which, together with (5.3), are all satisfied by ξ_1 and ξ_2 when the null space based on ξ_1, ξ_2 remains parallel. Actual determination of a V_4 which admits a 2-dimensional parallel null space would perhaps require more specific description of the axioms which, however, shall not be attempted here.

6. APPLICATIONS.

In looking for an example of a V_n in which the axioms given in §§1-3 may be satisfied, it is only natural to think of the complex n -dimensional vector space where, if the vectors λ, μ are given by the ordered n -tuples of complex numbers

$$\lambda = (l_1, \dots, l_n), \quad \mu = (m_1, \dots, m_n),$$

the sum and product of them are defined, as usual, by

$$\lambda + \mu = (l_1 + m_1, \dots, l_n + m_n),$$

$$a\lambda = (al_1, \dots, al_n), \quad \lambda\mu = l_1m_1 + \dots + l_nm_n.$$

Therefore the results established in §§2 and 3, some of them interesting enough, hold in this vector space,—a fact which I have not come across anywhere before. In the complex (unitary) space, the orthogonality condition is usually modified as $\lambda\bar{\mu} = 0$, where $\bar{\mu}$ is the conjugate complex of μ , so that only the vector O is self-orthogonal.

The all-round important application, however, lies in Riemannian geometry. Let V_n be the contravariant vector space at a point of an n -dimensional Riemannian manifold whose metric is not necessarily positive-definite and the matrix of whose fundamental tensor, viz. $[g_{ij}]$, is of rank n . Obviously F is the scalar field at the point and the axioms of §1 are satisfied. Axioms of §§2 and 3 are satisfied when the product of the vectors λ, μ are defined, as usual, by

$$g_{ij}\lambda^i\mu^j = g^{ij}\lambda_{ij}\mu_j = \lambda^i\mu_i = \lambda_i\mu^i.$$

Define now the functional of λ as the tensor $\lambda^i_{,j}$ or $\lambda_{i,j}$, according as the vector λ is taken in the contravariant or in covariant form, where the comma denotes covariant derivative with respect to Levi-Civita parallelism (or any parallelism for which the covariant derivative of the g_{ij} is zero). Then finally, the axioms of §4 are satisfied when the contravariant (or covariant) vector (α, λ) is defined by

$$(\alpha, \lambda) = \alpha^j\lambda^i_{,j} \text{ (or } \alpha^j\lambda_{i,j}).$$

As to what has been stated about the consequences of these axioms, it may be pointed out that if $f(x)$ is any function of an element x of F (e.g., $\lambda^i_{,j} = f(\lambda^i)$) satisfying the conditions

$$f(x+y) = f(x) + f(y) \text{ and } f(xy) = xf(y) + yf(x),$$

then $f(z) = 0$, where the element z belongs to the prime field of F .

The definition of parallelism in §5 follows that given by Walker (Walker, 1949). Regarding equations (5.2) and (5.3) we have only to say that (see Ruse, 1949)

$$c_{12} = \alpha^j \xi^i_{1,j} \xi_{2|i},$$

$$(\beta, (\alpha, \xi_1)) = \beta^k \{ \alpha^j_{,k} \xi^i_{1,j} + \alpha^j \xi^i_{1,jk} \} = ((\beta, \alpha), \xi_1) + \beta^k \alpha^j \xi^i_{1,jk},$$

$$(\alpha, \xi_1)(\beta, \xi_2) = \beta^k \alpha^j \xi^i_{1,j} \xi_{2|i,k} = \beta^k \alpha^j \{ (\xi^i_{1,j} \xi_{2|i})_{,k} - \xi^i_{1,jk} \xi_{2|i} \}.$$

Therefore $c_{12} = 0$ for all α implies $\xi^i_{1,j} \xi_{2|i} = 0$ and hence gives

$$(\beta^i_{,j} (\alpha, \xi_1)) \xi_2 = -(\alpha_1, \xi_1)(\beta, \xi_2) = \beta^k \alpha^j \xi^i_{1,jk} \xi_{2|i}.$$

Interchanging α, β and subtracting,

$$\begin{aligned}(\beta, (\alpha, \xi_1))\xi_2 - (\alpha, (\beta, \xi_1))\xi_2 &= (\beta, \xi_1)(\alpha, \xi_2) - (\alpha, \xi_1)(\beta, \xi_2) \\ &= \beta^k \alpha^j R_{hijk} \xi_1^h \xi_2^i,\end{aligned}$$

where R_{hijk} is the Riemann tensor, when the parallelism is that of Levi-Civita.

In conclusion it may be mentioned that the theorems given in this paper have been obtained in the sphere of Riemannian geometry by Ruse and Walker, while my task has been to provide an algebraic background of their theory.

ABSTRACT.

In this paper finite-dimensional vector space over a field satisfying certain axioms has been considered. Defining product of vectors in an abstract way so that the vector space admits null-vector, other than the zero-vector, an interpretation is obtained in §2 of the known result of matrix algebra that ASA^T can be a diagonal matrix D , where S is symmetric, A is non-singular and A^T is its transposed, and that the number of non-zero diagonal terms in D is invariant for all A , and also of the consequential nullity; an interpretation from the vector space point of view is also obtained in §3 of a class of permutation matrices. Finally, by introducing a certain notion of invariance of subspaces in §4 an attempt has been made to find an application in §6 of the theory of parallel field of vector spaces of Ruse and Walker.

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STUDIES ON CYTOCHEMISTRY OF HORMONE ACTION.

PART XII. THE EFFECT OF ADRENOCORTICOTROPHIC HORMONE (ACTH) ON THE DISTRIBUTION OF ALKALINE PHOSPHATASE IN THE ADRENAL CORTEX OF THE CAT

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INTRODUCTION.

Recent studies are making it increasingly evident that the alkaline phosphatase is an important constituent of the adrenal cortex and that the distribution of this enzyme undergoes profound changes under hormonal influence. Thus, Elftman (1947) noted that the phosphatase disappears from the adrenal cortex of the gonadectomized mice of both sexes. Androgen therapy in operated animals restores the enzyme to its original distribution and intensity. Soulaire *et al.* (1949) reported similar results on rats. Dempsey *et al.* (1949) observed that after hypophysectomy the phosphatase disappears from the fasciculata and the reticularis of the rat's adrenal cortex but persists in the glomerular zone. Replacement therapy with whole pituitary powder causes a reappearance of the enzyme and a return to a condition approximating that of the normal gland. Estrogen and androgen cause a marked reduction in alkaline phosphatase activity in the adrenal cortex of the pigeon (Kar, 1950) but progesterone and desoxycorticosterone acetate treatments are associated with a spectacular mobilization of the enzyme in the gland (Kar, 1951a). Adrenaline behaves in a manner similar to the sexual hormones and reduces the concentration of alkaline phosphatase in the adrenal cortex of this species to a marked extent. Gonadotrophic hormone therapy in adrenaline-treated animals is only partially effective in preventing this enzymatic loss (Kar, 1951b). Recently, Kar and Ghosh (1952a) made an extensive study of the effect of different steroid hormones and serum gonadotrophin on the distribution of this enzyme in the guineapig's adrenal cortex, and in all cases an overall reduction in phosphatase activity is clearly indicated.

Since ACTH is a most important controlling factor in the functional activity of the adrenal cortex, it seemed of interest to study the effects of this hormone on the distribution of alkaline phosphatase in the cortical tissues. Further, in view of the considerable cytochemical and biochemical evidences showing the stimulation of the adrenal cortex after ACTH treatment (Selye, 1950), it seemed desirable to explore whether any physiological relationship existed between the hormone-stimulated gland and alkaline phosphatase activity. The cat served as our animal of choice in this study, as the presence of this enzyme has not hitherto been reported in the adrenal cortex of this species.

EXPERIMENTAL PROCEDURE.

Eight female kittens of approximately similar weight were used in this investigation. Four of the animals were injected intramuscularly with ACTH ('Corticotropin' Wilson Lab., Chicago, U.S.A.) at the rate of 2 U.S.P. units (in 0.5 c.c. of sterile distilled water) twice daily. The injections were given at an interval

of 12 hours. This dosage was continued for 5 days and from the 6th day it was increased to 3 injections of 2 units daily spaced at an interval of 8 hours. This rate was maintained for 7 days, after which the animals were sacrificed. In all, the period of treatment lasted 12 days during which a total of 62 units of the hormone were administered per animal. The animals tolerated the drug well and the treatment period passed off without evoking any visible untoward reactions. The control animals were injected intramuscularly with 0.5 c.c. of sterile distilled water in a similar manner and for the same period. The animals were maintained in cages under uniform husbandry conditions throughout the duration of the experimental period.

Autopsy followed 24 hours after the final injections. The animals were killed by a blow on the head in order to allow least possible ante-mortem trauma to the adrenals. The glands were fixed and processed according to the technique of Gomori as laid down by Glick (1949). The sites of phosphatase activity in the tissue sections are marked by the deposition of cobalt sulfide in fine black granules. In order to allow critical observation of the cobalt sulfide deposits, no counterstain was used. The sections were dehydrated and mounted in the usual manner.

RESULTS.

Control.—The capsule of the gland is negative for the phosphatase. In the glomerular zone the nuclei stain positively but the cytoplasm of the component cells gives only a faint reaction. The endothelium of the blood sinusoids in this region, however, stains in a strong positive manner. In the outer fasciculata the distribution of the enzyme is more or less similar to that of the glomerular zone but the parenchymal cells of the inner part of this zone show intense phosphatase activity (Pl. XXI, fig. 1). The endothelium of the fascicular sinusoids also takes up deep stain. The reticularis appears to be the maximum reactive zone. The nucleus and the cytoplasm of the component cells give strong positive reactions for phosphatase activity and in some cells the reactions are so intense that the cellular contours are totally obscured by granular deposits of cobalt sulfide. The endothelium of the sinusoids and the occasional macrophages in this region also show strong positive reactions for the enzyme (see Table I).

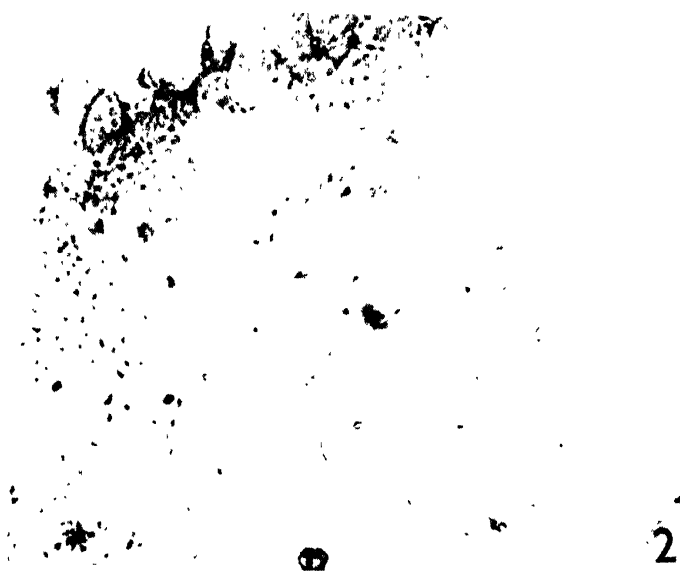
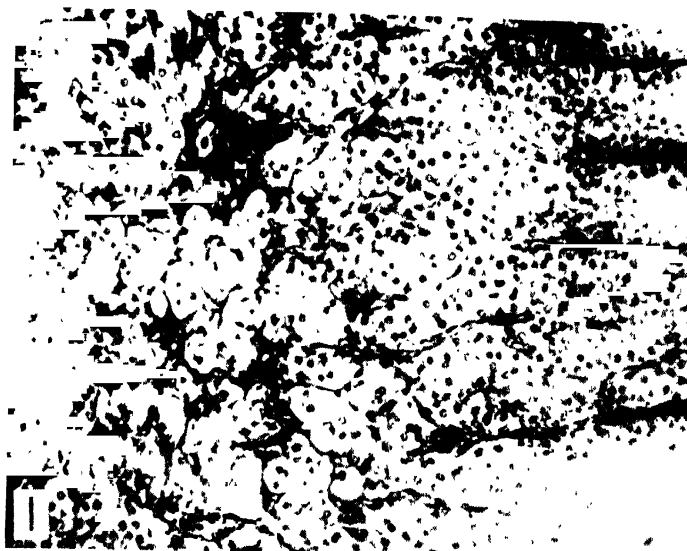
TABLE I.

The distribution of alkaline phosphatase in the adrenal cortex of normal and ACTH-treated cats.

			Control	ACTH-treated
<i>Capsule</i>	..	..	—	—
<i>Zona glomerulosa:</i>				
Parenchymal cells	..	..	+ +ⁿⁿ	—
Blood sinusoids	..	..	—	+ +^r
<i>Zona fasciculata:</i>				
Parenchymal cells (outer)	..	..	+ +ⁿⁿ	—
Parenchymal cells (inner)	..	..	+ +	—
Blood sinusoids	..	..	+ +	—
<i>Zona reticularis:</i>				
Parenchymal cells	..	..	+ +	+ⁿ
Blood sinusoids	..	..	+ +	+ +

Legend:—

- + + = Strong alkaline phosphatase activity.
- = No alkaline phosphatase activity.
- + +ⁿⁿ = Intense reactions in the nucleus but no activity in the cytoplasm.
- +ⁿ = Moderate reactions only in the nucleus.
- + +^r = Positive reactions but rare.



(All figures are photomicrographs and are magnified 100.)

- FIG. 1. Section through the adrenal cortex of a control cat. Note the distribution of alkaline phosphatase. The zona reticularis is on the left side of the illustration.
- „ 2. Section through the adrenal cortex of an ACTH-treated cat. Note the disappearance of alkaline phosphatase from the fasciculated and persistence of reactions in the glomerular sinusoids. The reticular zone is not shown in the illustration.

ACTH-treated.—Macroscopically, the adrenals are considerably enlarged in size and this could be ascribed mainly to the hypertrophy of the cellular parenchyma of the fascicular zone. The glomerulosa shows no histological response to ACTH treatment. Cytochemically, a pronounced reduction in phosphatase activity is clearly evident upon microscopical examination (Pl. XXI, fig. 2). The capsule gives a negative reaction for the enzyme and such is practically also the case with the glomerular cells. Occasional sinusoids in this zone, however, continue to give a positive reaction in the endothelium. The parenchymal cells and the sinusoids of the fasciculata are totally devoid of any phosphatase activity. In the reticularis, the component cells exhibit moderate reactions only in the nucleus but the cytoplasm is negative for the enzyme (Table I). The endothelium of the sinusoids in this region retains strong phosphatase activity.

DISCUSSION.

The pattern of distribution of alkaline phosphatase in the adrenal cortex of the cat merits a brief comment. The few mammalian species which have been studied show a remarkable diversity in the manner of distribution of this enzyme (Kar and Ghosh, 1952*b*). The details of phosphatase distribution in the cat, however, indicate that the pattern is somewhat intermediate between the male rat and the rhesus monkey.

It is now a well-established fact that under conditions of stress the adrenal cortex is markedly hypertrophied and this is irrevocably associated with increased secretion of corticosteroids (Selye, 1950). Injection of ACTH in an otherwise normal animal elicits cortical changes simulating those which occur in stress. The cytochemical changes which follow ACTH treatment are undoubtedly indicative of an active release of corticosteroids (Bergner and Deane, 1948). Chemical studies also demonstrate lucidly a similar release of corticosteroids after injection of this hormone (Sayers *et al.*, 1945 and 1946; Levine, 1945). Moreover, the cytochemical reactions indicative of active steroid release, like decrease in the amount of sudanophilic and birefringent lipids, are given exclusively by the fasciculata which clearly typifies the released hormones as corticosteroids (Bergner and Deane, 1948). It may be pointed out that the results of brisk cytochemical studies in recent years have targetted the fasciculata as the seat of production of corticosteroids and glomerulosa as the producer of desoxycorticosteroids (Greep and Deane, 1949). The latter zone, however, fails to share the cytochemical modifications which ensue in the fasciculata under conditions of stress or after ACTH injections (Bergner and Deane, 1948).

If the findings recorded in this paper are reckoned against those mentioned above, some interesting correlations are indicated. In the cat also, the cortex shows pronounced hypertrophy after ACTH treatment and on histological analysis this could be ascribed mainly to the enlargement of the cellular parenchyma of the fascicular zone. The glomerular zone, however, shows no response and concomitant with this, the Gomori reactions totally disappear from the fasciculata. Since the phosphatases are importantly concerned with the metabolism of lipids (Moog, 1946; Dempsey and Wislocki, 1946 and others), it is not unlikely that the enzyme under study is involved in the endocellular mechanism responsible for the formation and metabolism of this vital constituent of the adrenal cortex. On the basis of this concept, it may be reasonable to postulate that the disappearance of alkaline phosphatase from the fasciculata of our material is associated with rapid metabolism and the subsequent decline in lipid level, which invariably occur after ACTH treatment. Besides, it is now satisfactorily established that the steroid hormones of the adrenal cortex are rigidly associated with its lipid fraction and the depletion in the level of this substance reflects a heightened secretory activity of the gland, as evidenced by the accelerated tempo of release of the steroids (Greep

and Deane, 1949). The present findings would suggest that alkaline phosphatase fits into this syndrome and influences the physiology of the adrenal cortex in an indirect manner. The occurrence of weak phosphatase reactions in the outer fasciculata of the control animals would indicate an active metabolism of lipids and output of steroids from this area alone. This tends to subscribe an interesting evidence to the finding that this is the only secretory portion in the middle zone of the cat's adrenal cortex (Bennett, 1940).

SUMMARY.

Intramuscular injections of adrenocorticotrophic hormone (ACTH) in the cat cause a pronounced hypertrophy of the cellular parenchyma of the fasciculata and total disappearance of phosphatase activity from this adreno-cortical zone. The enzyme is probably concerned with the metabolism of cortical lipids with which the steroids occur in rigid association. The phosphatase responses of the fasciculata to ACTH suggest a relationship of this enzyme to an accelerated rate of lipid metabolism and corticosteroid release.

ACKNOWLEDGEMENT.

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COLLOIDAL COLOURED SILICA GLASS

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INTRODUCTION.

The colour of gold-ruby glass provided a very fascinating problem to the scientists in a very early period of the present century and it was Zsigmondy, who by the ultramicroscopic investigation showed the presence of colloidal gold in gold-ruby silicate glass. He also made a notable contribution to the various problems of ruby glass such as growth of colour in ruby glass, variation of the particle size of gold with heat treatment, relation between colour and the particle size of gold, etc. G. Tammann and H. Schrader (1927) studied the temperature at which glass containing gold becomes red, because finely divided gold dissolved in a molten silicate glass imparts no colour to the latter when rapidly chilled. Practically speaking, some early observations of interesting results of ruby glass stimulated research in glass in many directions. Literature about ruby glass is voluminous and Weyl (1945) has made an excellent summary of the previous works on ruby glass. In the present investigation use has been made of the X-ray diffraction method in collaboration with other chemical and physical methods so as to clarify and to advance some of the interesting points and views of the colloidal coloured silica glass. In the case of our previous investigation of Au, Ag and Pt glasses, X-ray study of the borate or B_2O_3 glass specimens was facilitated much by the appreciable solubility of the noble metal in those media as well as by the low absorption coefficient of the atoms of the glass base, whereas in the case of silicate glass, we are encountered with some difficulties such as the low solubility of noble metal, the high absorption coefficient of the atoms of the silicate glass, etc. However, the investigation of soda-silica glass containing gold and silver as a dispersed phase is expected to give some valuable information.

EXPERIMENTAL.

It is well known from a very early period that a good ruby colour can be easily flashed out in various types of silicate glass with a very small amount of gold, provided a special case is taken during the process of reheating the glass specimen. Similarly silver can be used to obtain yellow colour but the amount of Ag required is much greater than gold.

It has been stated before that gold or silver has a very low solubility in silicate glass, as for example in a soda-lime-silica glass ($SiO_2 = 72\%$, $Na_2O = 17.1\%$ and $CaO = 11\%$) gold can be dispersed to the extent of only 0.02% and with such a low content of gold, no useful purpose would be served by making the X-ray diffraction study of that specimen. However, we have found that in soda-silica glass with 25% Na_2O content, gold and silver can be dispersed to the extent of about 0.20 and 1.25 in weight per cent respectively and those specimens are quite suitable for our present purpose. Melt is prepared in platinum crucible at $1100^\circ C.$ with no reducing agent and each specimen is heat-treated at $700^\circ C.$ for half an hour. Similarly specimen of gold-ruby silica glass containing a small amount of PbO is

prepared. The vitreous limit of each glass composition, as derived from the chemical analysis, is given in the following table:—

Glass composition	Au or Ag content in weight per cent	
Au-soda-silica glass	..	0.20
Ag-soda-silica glass	..	1.25

Experimental details for taking X-ray photograph of a very thin sample stick are the same as in the previous case and all photographs are taken in a cylindrical camera of radius 2.97 cm. in Cu $K\alpha$ radiation. The content of noble metal in the respective sample is as follows:—

Au- $\text{Na}_2\text{O-SiO}_2$ series—Sp. 1-0.075%, Sp. 2-0.170%, Sp. 3-0.20%;

Ag- $\text{Na}_2\text{O-SiO}_2$ series—Sp. 4-0.75%, Sp. 5-1.15%.

The X-ray photograph of comparatively high Au content sample reveals the presence of both bands and lines, whereas in silver glass only bands are found in the X-ray picture. All X-ray photographs are given in Plate XXII and the diffraction angle of each band along with the relative intensity ratio is as follows:—

$10^\circ 51'(s)$, $16^\circ 2'(m)$.

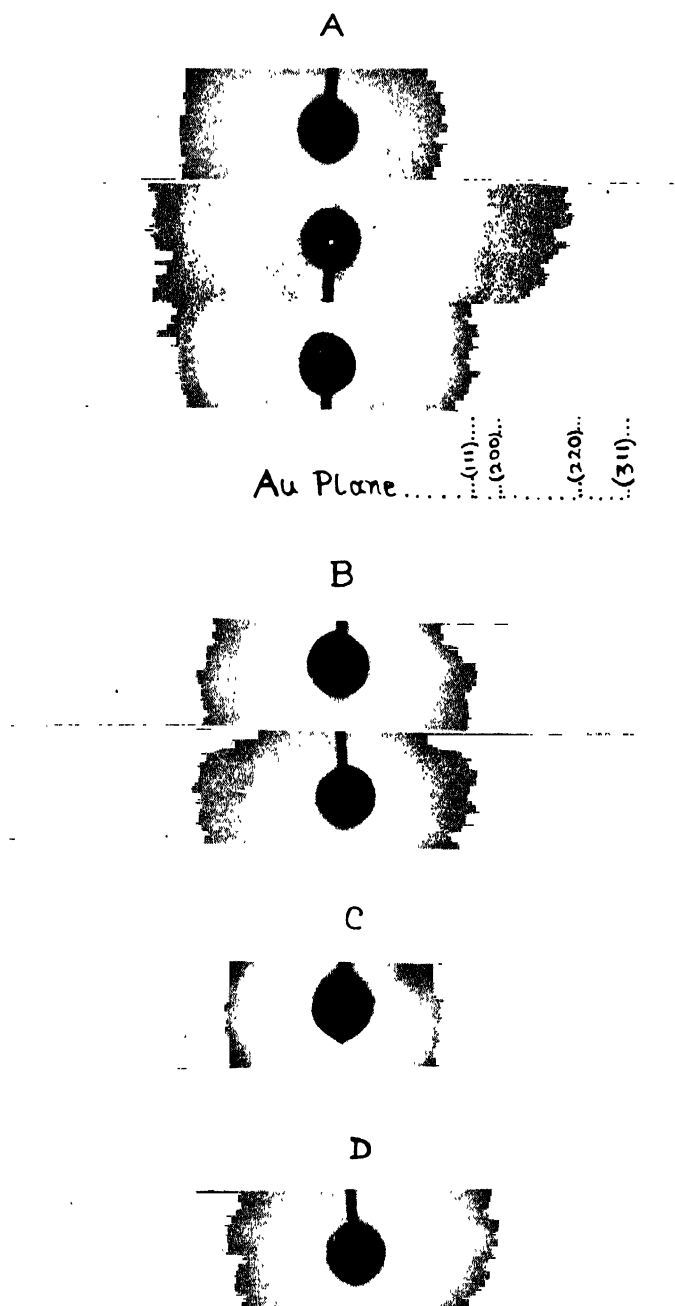
The lines present in the X-ray photograph of gold sample are broad and weak and those lines have been identified are due to gold, as is evident in the following table:—

Au-soda-silica glass.

Pure Au			Sp. No. 2		Sp. No. 3	
θ	Plane	Intensity	θ	Intensity	θ	Intensity
$19^\circ 7'$	(111)	1.00	$19^\circ 6'$	mw	$19^\circ 6'$	m
$22^\circ 17'$	(200)	0.53	$22^\circ 12'$	w	$22^\circ 12'$	mw
$32^\circ 21'$	(220)	0.33	$32^\circ 14'$	vw	$32^\circ 14'$	w
$38^\circ 53'$	(311)	0.40	$38^\circ 47'$	vw	$38^\circ 47'$	w
$41^\circ 2'$	(222)	0.09				
$49^\circ 7'$	(400)	0.03				
$55^\circ 27'$	(331)	0.09				
$57^\circ 48'$	(420)	0.07				

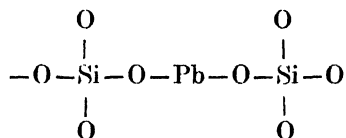
Although the content of silver in silver glass is much greater than the corresponding gold sample, yet no lines of Ag are found in the diffraction pattern of glass, possibly the major portion of Ag exists in ionic and atomic form in the glass. However, on prolonged heat treatment at 700°C . for six hours the yellow colour deepens and the X-ray photograph of the specimen reveals the presence of the lines of Ag.

In connection with our work on soda-silica glass containing noble metal, the action of PbO on the above glass system is also studied. It is well known that a small amount of PbO in glass batch increases the solubility of the noble metal and at the same time the brightness and the depth of the colour are improved much. A comparative study by X-ray method of two specimens of the same composition, containing about 0.2% Au and of same thermal history, while one of them contains about 0.2% PbO , reveals that the crystallites of gold which were present in the original sample are no longer found in the specimen which contains PbO . This evidently indicates that the presence of Pb ions in glass affects the speed of crystal growth of dispersion of gold in the above glass base, although the colour of the glass



- A. Au-soda-silica glass samples. Sp. Nos. 1 to 3.
 B. Ag-soda-silica glass samples. Sp. Nos. 4 and 5.
 C. Ag-soda-silica glass, heat-treated for a long period.
 D. Au-soda-silica glass containing lead oxide.

is improved much. Consequently it is worth while to discuss the rôle of Pb ions in the glass structure. Further it is known that the presence of Pb produces some good properties in glass, such as high refractive index, etc., and that is due to the fact that the Pb atom is easily polarizable. Pb glasses may have structure similar to soda-silica glass, two atoms of Na being replaced by one Pb atom but in a very high Pb content glass, it is suggested that Pb atoms are joined with Si atom in the following way:—



where Pb atom actually takes part in the formation of network. It is necessary to mention here that from the point of the criteria of the glass-forming oxide, Pb ion is incapable of taking part in the network, but experimentally Pb glass of molecular composition Pb_2SiO_4 has been found. Such peculiar behaviour of PbO in glass has been explained by Fajans (*J. Am. Ceram. Soc.*, **31**, 105, 1948) as due to the high polarizability of Pb ions.

ABSTRACT.

The method of formation, X-ray study, the influence of lead oxide (PbO) and the effect of prolonged heat treatment of colloidal coloured glass of Ag and Au in silicate glass base have been studied.

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COLLOIDAL COLOURED SILVER GLASSES

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INTRODUCTION.

The study of colours in glass has provided an interesting problem. Colours may be due to the solution of metallic cations or due to the colour of the fine suspension in glass. In our previous paper—X-ray study of colloidal coloured glasses—our investigation was confined on colloidal coloured glasses of Au and Pt in B_2O_3 , borax and Lindemann glass bases, where the colloidal particle of Au and Pt had been identified in the respective glass specimen by the X-ray diffraction method along with some interesting observations. In the present case that line of investigation has been extended to colloidal coloured silver glasses.

Silver and some salts of silver are capable of producing colloidal coloured glasses. Weyl (1945), Kreidl (1942), and several other workers have studied silver glasses. In the previous paper the investigation on colloidal coloured glasses of Au and Pt in B_2O_3 , borax and Lindemann glass bases was made. Silver can exist in the ionic form along with the atomic or elemental state in the glass base, whereas Au or Pt exists mostly in the elemental state in the glass base. Almost all Au and Pt salts are unstable at the firing temperature of the glass melt, whereas some salts of Ag, such as AgCl, only volatilize at white heat without being decomposed. The ionic radius of Ag is 1.14 \AA and this can be compared with the ionic radius of Na and K which comes to about 0.98 \AA and 1.33 \AA respectively. Consequently the investigation on the following glass systems is expected to reveal some interesting results: Ag- B_2O_3 , Ag-borax, Ag-Lindemann and AgCl-borax glass system. Amongst the above series, AgCl-borax system has been purposely included so as to study the effect of the intruder substance which has two dissimilar atoms from those of the glass base and which is capable of forming a transparent coloured glass. The present investigation is confined mainly to the following aspects of the problem: (1) vitreous limit, (2) colour and (3) X-ray analysis of glass specimens.

EXPERIMENTAL.

All glass specimens have been prepared in Pt crucible at 1000°C . and in the preparation of glass specimen all A.R. quality reagents, such as silver nitrate, silver chloride, B_2O_3 , $BeCO_3$, Li_2CO_3 , have been used. Each glass sample was heat-treated at 550°C . for half an hour. The silver content of each specimen has been determined by the Vollhard method. The vitreous limit of different glass compositions is as follows:—

Glass composition		Maximum concentration in weight per cent
Ag- B_2O_3	..	4.00
Ag-borax	..	5.60
Ag-Lindemann	..	2.75
AgCl-borax	..	5.75

The high solubility of silver in each glass base compared with similar Au and Pt glass system is due to the less noble character of silver. Amongst the silver glasses, the low solubility of Ag in Lindemann glass is due to the composition of glass which contains two cations Li and Be, each of which has a very high charge density.

The colour of silver glass is yellow and an attractive violet colour is developed in a sample containing AgCl. Yellow Ag glass on prolonged heating at 550°C. for 6 hours turns deep brown. Unlike Au or Pt glass specimens, exposed portion of Ag glass towards X-rays shows a slight variation in colour from the rest of the unexposed specimen. Ordinarily in a desiccator the colour of the glass specimens remains unchanged, only the surface of the glass specimen turns slightly brown after a long period of standing. In a sample of high silver or silver chloride content, there is a gradual transformation of yellow or violet colour into dark brown or dark grey colour and that change is accompanied by increase in opalescence of the glass specimen.

A few representative samples of each series have been taken up for the X-ray study. Experimental details and particulars are the same as in the case of Au and Pt glass. All samples have the same thermal history, they are kept at 550°C. for half an hour and then slowly cooled down to the room temperature. All X-ray photographs have been taken in the same camera ($r = 3.90$ cm.) in Cu $K\alpha$ radiation under the same conditions with a view to making a comparative study of the above glass systems.

The X-ray diffraction study of silver glasses reveals the presence of bands in all cases and in some samples both bands and lines are present. Again there is a variation of intensity and the nature of both band and line even amongst the samples of the same series.

Amongst silver glasses studied here, the existence of colloidal Ag in Ag-B₂O₃ and Ag-borax series is found, and the lines of Ag in the diffraction picture of Ag-Lindemann glass are almost absent. Again in AgCl-borax glass, the crystallites of AgCl can be readily identified in the X-ray picture.

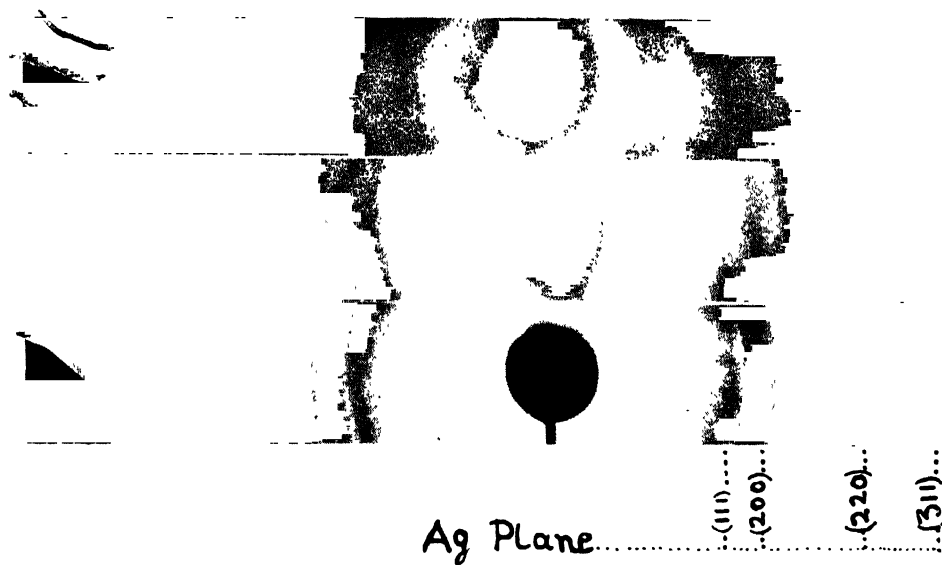
The diffraction angle of each band along with the relative intensity of the silver samples is given in the following table:—

Glass composition	Sp. No.	Concentration in weight per cent	θ_1	Intensity	θ_2	Intensity	θ_3	Intensity
Ag-borax	1	0.75	9° 21'	s	14° 19'	m	22° 35'	mw
	2	1.50	9° 21'	s	14° 19'	m	22° 35'	mw
	3	3.5	9° 21'	w				
Ag-Lindemann	4	1.70	10° 39'	s	21° 29'	w		
	5	0.75	10° 52'	s	21° 34'	w		
	6	2.75	10° 47'	s	21° 34'	w		
	7	3.20	10° 52'	s	21° 39'	w		

Usually the lines present in the X-ray photograph of silver glass shown in Plate XXIII are weak and those lines have been identified as due to silver in the following way.

It has been stated before that Ag can exist in the ionic, atomic and metallic state in all possible combinations in the glassy matrix and the relative proportion of each state is determined by the composition, and the temperature of the softening range of the glass base, as well as by the thermal history of the specimen. As all glass samples have been prepared under the same conditions, the variation in

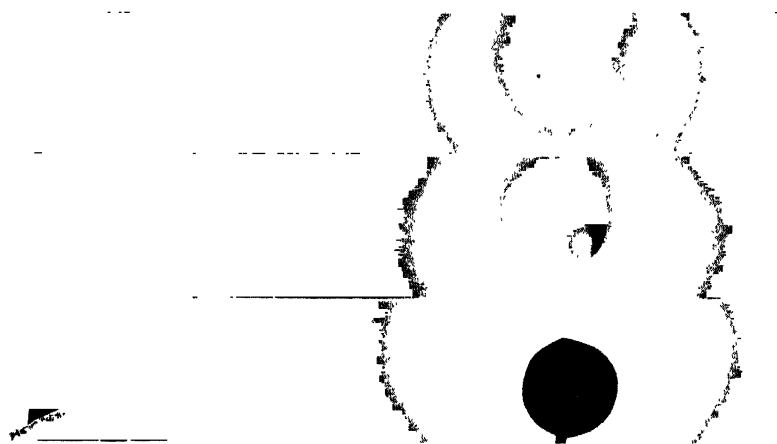
A



B



C



- A. Ag-borax glass samples. Sp. Nos. 1 to 3.
- B. Ag-Lindemann glass sample. Sp. No. 4.
- C. Ag-B₂O₃ glass samples. Sp. Nos. 5 to 7.

Pure Ag			Ag-borax			Ag-Lindemann			Ag-B ₂ O ₃		
			Sp. 2			Sp. 3			Sp. 4		
			θ	Intensity		θ	Intensity		θ	Intensity	
18° 35'	(111)	1.00	18° 32'	m	18° 37'	s	18° 37'	w	18° 37'	m	s
22° 11'	(200)	0.53	22° 13'	mw	22° 13'	m	22° 13'	..	22° 13'	mw	m
32° 12'	(220)	0.27	32° 8'	w	32° 8'	mw	32° 8'	..	32° 13'	w	mw
38° 41'	(311)	0.53	38° 45'	mw	38° 39'	m	38° 45'	..	38° 45'	w	m
40° 46'	(222)	0.05	..	..	40° 46'	w	40° 46'	..	40° 46'	vw	w
48° 54'	(400)	0.01	..	..	48° 51'	w	48° 51'	..	48° 51'	vw	w

glass composition plays a leading rôle in the distribution of different forms of silver in the glass medium.

It is also observed that by prolonged heat treatment of silver glass, some interesting results are obtained. For that purpose Ag-borax specimen, which gives practically no lines of Ag in the X-ray photograph, is subjected to long temperature treatment for 6 hours at 550°C. A deep brown glass is obtained and the X-ray photograph of that specimen reveals the presence of big crystallites of Ag which is indicated by the lines in the diffraction pattern.

The X-ray picture of AgCl-borax samples reveals the presence of both bands and lines with the exception of a very low AgCl content specimen where bands are only found. The diffraction angle with the relative intensity of each band has been shown in the following table :—

Glass Composition	Sp. No.	Concentration in weight per cent	θ	Intensity	θ_2	Intensity	θ_3	Intensity
AgCl-borax	8	0.15	9° 21'	s	14° 8'	m	22° 24'	mw
	9	1.20	9° 21'	s				
	10	3.20	9° 21'	w				

The lines in the X-ray picture of the AgCl-borax series are due to AgCl as is quite evident in the following table :—

AgCl-borax.

Pure AgCl			Sp. No. 9		Sp. No. 10	
θ	Plane	Intensity	θ	Intensity	θ	Intensity
13° 55'	(111)	0.40	13° 51'	mw	13° 57'	m
16° 9'	(200)	1.00	16° 3'	m	16° 9'	s
23° 8'	(220)	0.75	23° 1'	mw	23° 7'	ms
27° 28'	(311)	0.20	....	..	27° 27'	mw
28° 46'	(222)	0.25	....	..	28° 44'	mw
33° 47'	(400)	0.09	....	..	33° 47'	w
37° 19'	(331)	0.06	....	..	37° 16'	w
38° 28'	(420)	0.20	....	..	38° 28'	mw
42° 54'	(422)	0.13	....	..	42° 53'	w
46° 18'	..	0.01				

Thus it is found that AgCl remains dispersed in colloidal form due to the different actions of AgCl towards the glass base. The behaviour of different salts towards a particular glass base depends primarily on the size, polarizability, and the nature of the bond between the ions of the salt as well as those of the constituents of the glass base. The ionic character of the bond of AgCl is only 36% owing to the high covalent character of AgCl bond and the difference in the ionic radius and polarizability of the chlorine and oxygen ion, the possibility of AgCl taking part in the formation of the glass-forming units is very remote, because that would involve at the first the breaking of the AgCl bond.

D



AgCl Plane

(111)
(200)
(220)
(220)
(311)

D. AgCl-borax glass samples. Sp. Nos. 8 to 10.

ABSTRACT.

The state of existence of Ag in B_2O_3 borax and Lindemann glass and its influence on the structure of the glass base have been studied along with other interesting properties such as the method of formation, vitreous limit, colour, etc. Similarly AgCl-borax glass specimens have also been studied. In the course of the above investigation the crystallite of the dispersoid has been identified by the X-ray diffraction study.

ACKNOWLEDGEMENTS.

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SOME OBSERVATIONS ON THE PLAGIOCLASE TWINNING IN CHARNOKITIC ROCKS

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INTRODUCTION.

The petrology of the Eastern Ghats has been under investigation from a long time. The two major rock suites met with in this area are khondalites and charnockites, the latter mostly intruded into the former. The petrogenesis of charnockites is still a disputed problem. As statistical investigations on the plagioclase twinning and its correlation with the origin of the rock types are now an interesting branch of mineralogical petrology, an attempt is made to study the twinning in plagioclase feldspars of the charnockites of the Eastern Ghat region with a view to understanding the modes of origin of the rocks.

PREVIOUS LITERATURE.

Literature pertaining to this problem is quite vast, the work of Coulson (1931), Barber (1936), Emmons and Grates (1943), Chapman (1936), Donnay (1943) and Dolar-Mantuani (1952) being significant in this respect. Reference to the plagioclase twinning was made in some studies on the Deccan traps and on the intrusions in Cuddapah and Kurnool rocks. So far no work has been carried out in India exclusively on the plagioclase feldspars as to throw light on the origin of the rocks.

In recent years Gorai (1950) has made classic contributions in this direction. His chief observations on plagioclase feldspars of igneous rocks are: (1) in all undoubted igneous rocks untwinned plagioclases are subordinate to twinned ones, (2) the two groups of twins represented in them are C-twins, which include carlsbad, albite-carlsbad, and the rarer manebach, baveno, ala and albite-ala types and the A-twins including albite and pericline types, and (3) relative abundance of twinned grains; A-twins and C-twins in plagioclases correspond to igneous rocks. Turner's (1951) observations on the plagioclase feldspars of metamorphic rocks show that there is comparative rarity of twinning, prevalence of simple twins consisting of a few sub-individuals and predominance of albite and pericline twins, carlsbad being subordinate and complex twin combinations being absent. The study of twinning in plagioclase feldspars though not conclusive in itself is suggestive and aids in solving problems of petrogenesis.

METHODS OF STUDY.

Twinning, extinction angles, and optic axial angles have been determined by the use of the four-axis Federov's Universal stage and the results are interpreted by the method of Duparc and Reinhard. Rittman's Zonal method has also been used for determining the twinning in plagioclase feldspars. The acid, intermediate and basic members of the charnockite suite of rocks were collected from various localities in the Eastern Ghat region and were studied. The study of plagioclase feldspars with particular reference to their twinning forms the subject-matter of this paper.

TWINNING IN PLAGIOCLASES.

Plagioclase feldspars in these rocks are generally twinned. The untwinned ones are relatively abundant in the acid, and intermediate varieties with practically none represented in the basic rocks.

In the acid members of the charnockite suite of rocks most of the plagioclase feldspars are untwinned. The twinning where present is mostly on the pericline, acline and albite laws. In the specimens from Chromepet and Salur except for a few grains twinned on the baveno law, the others exhibit twinning on the pericline and albite laws. In the rock from Salur, there is not even a single grain entirely devoid of twinning. The Ananthagiri and Pallavaram sections reveal the albite law subordinating the pericline law. Microsections of the Waltair samples show that the acline and pericline are equally represented, with a few on the manebach and albite laws. The table given below (Table I) presents the observations on the acid charnockites from different areas.

TABLE I.

Locality of specimen	Normal Twins			Parallel Twins	
	Baveno	Manebach	Albite	Pericline	Acline
Chromepet: (80° 8'; 12° 56')	Tr	..	G	G	..
Salur: (83° 12'; 18° 31')	Tr	..	G	G	..
Ananthagiri: (83° 0' 30"; 18° 14') .. ..	..	..	G	A	..
Pallavaram: (80° 9'; 12° 58') .. ..	..	..	G	A	..
Waltair: (83° 19'; 17° 45') .. ..	..	Tr	Tr	G	G
Anorthite content	15-20%	15-25%	15-25%	20-25%	20-25%

A—abundant; G—good; F—fair; Tr—traces.

The intermediate charnockites have a jumbled assemblage of twinned and untwinned plagioclase feldspars, where the twinned ones—particularly the normal and parallel types—dominate. Of the normal types, twinning on albite and manebach laws is common and on baveno law is rare. Among the parallel twins, pericline, acline, and carlsbad are frequent and ala-A is rare. The specimens from Salur have albite and pericline with a few grains of baveno and carlsbad-A.

Intermediate charnockites from Nallambakkam and Vandalur present the albite and pericline laws besides acline, manebach and carlsbad-A. In the rock from Kondapalle the plagioclase feldspars are mostly twinned, the twins being pericline, acline and albite, manebach and carlsbad being subordinate. In just a few grains the complex twin albite-ala is seen. In the Ananthagiri rocks, the pericline dominates over the ala-A and carlsbad laws with traces of albite, manebach and acline twins. The specimens from Waltair have albite and pericline twins in equal amounts besides the ala-A, acline and manebach twins. Pallavaram sections reveal the pericline and albite twins with a few of carlsbad. The relative abundance of various laws in the intermediate charnockites is given in the following table (Table II) :—

TABLE II.

Locality of specimen	Normal Twins			Parallel Twins				Complex
	Baveno	Manebach	Albite	Pericline	Acline	Ala-A	Carlsbad-A	Albite-Ala
Salur: (83° 12'; 18° 31')	Tr	..	A	A	..	..	Tr	..
Nallambakkam: (80° 8'; 12° 50')	..	Tr	G	G	Tr	..	Tr	..
Vandalur: (80° 8'; 12° 54')	..	Tr	G	G	Tr	..	Tr	..
Kondapalle: (80° 32'; 16° 37')	..	Tr	F	F	F	..	Tr	Tr
Ananthagiri ..	..	Tr	Tr	A	Tr	F	F	..
Waltair ..	..	Tr	F	F	Tr	Tr	..	..
Pallavaram ..	..	..	G	G	..	.	Tr	..
Anorthite content	20%	20-25%	20-30%	25-40%	30-40%	40-45%	35-45%	50%

A—abundant; G—good; F—fair; Tr—traces.

The basic charnockites give altogether different results in regard to the twin laws of their plagioclase feldspars. Most of the feldspars show complex twinning. Parallel twins are also observed. The twin lamellae are wide with the prevalence of penetrating fine to coarse sub-individuals. The following are the twin laws observed in the plagioclase feldspars of these rocks: carlsbad-A and B, and ala-A and B of the parallel types, albite-carlsbad and albite-ala-B of the complex types. Specimens from Chromepet and Salur have the albite-carlsbad and albite-ala-B with a few grains twinned on carlsbad law. Rocks from Pallavaram, Kondapalle, Ananthagiri and Waltair also present the same twins as above, while in the specimens from Waltair the parallel twins are generally absent. The following table (Table III) summarises clearly the studies on the twinning of the plagioclase feldspars of the basic charnockites.

From a study of the tables given above it is evident that the normal twins are common in plagioclase feldspars having 15 to 25% Anorthite, the parallel twins in those with 20-50% Anorthite, and the complex twins in those with 50-65% Anorthite. The optic axial angle varies considerably, the range being from 70° over Z to 82° over X. The Anorthite percentages as deduced from these angles, with the help of the curves of Wright modified by Winchell, are very nearly the same as those obtained by the study of twinning and by other methods.

TABLE III.

Locality of specimen	Parallel Twins		Complex Twins	
	Carlsbad (A & B)	Ala (A & B)	Albite-Carlsbad	Albite-Ala-B
Chromepet ..	Tr	..	G	G
Salur ..	Tr	..	G	G
Kondapalle ..	..	Tr	G	G
Waltair ..	..	..	A	F
Pallavaram ..	..	..	A	F
Ananthagiri ..	..	Tr	A	F
Anorthite content..	40-45%	35-45%	60-65%	55-65%

A—abundant; G—good; F—fair; Tr—traces.

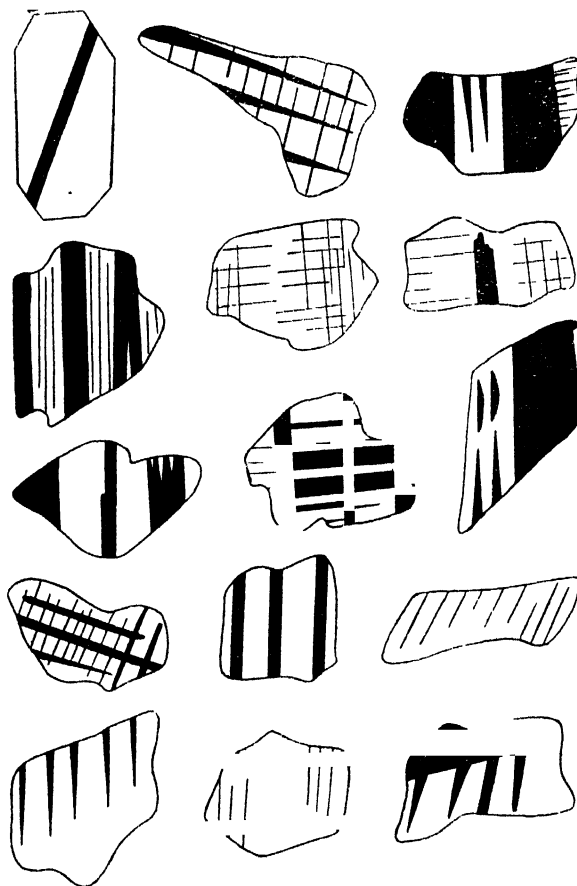
INTERPRETATION.

The rock specimens studied come from areas which have been geologically investigated earlier by others—who hold the view that the charnockitic rocks are derived from a basic magma which has intruded into the country rock—mostly khondalite. Later effects, such as contamination and metamorphism, might have caused the formation of charnockites of the acid and intermediate varieties. In the area south of Pallavaram the charnockites are believed to have been formed from a basic magma represented by norite resulting in the acid and intermediate varieties by assimilation with the paragneisses.

The plagioclase feldspars of the basic rock, as revealed earlier, are all twinned. All the grains of plagioclase feldspars are devoid of alteration, cracks, undulose extinction and such other features and are absolutely fresh. The commonest of the twins are of the complex types with very few representing the parallel types. All the twins present in this rock type are classed under C-twins. It may be, that the increase in the anorthite content of the plagioclase feldspar has some relation with the complexity of twinning. Perfectly developed sub-individuals of the plagioclase are numerous in the basic rocks. This may be due to twinning on more than one law during its formation, that is paragenetic twinning. It is thus suggestive that these rocks are igneous in origin.

The intermediate members have the twinned plagioclase feldspars dominating the untwinned ones and almost all the grains exhibit undulose extinction, cracks with alteration, and myrmeketic growths. Among the twinned grains the normal and parallel laws are common. Thus the twins present in these rocks fall under the C- and A-twins. A study of these plagioclases and their twinning suggests that the intermediate charnockites are perhaps the result of metasomatic processes involving addition of foreign rock material.

As regards the acid charnockites, they are constituted of untwinned plagioclase feldspars with a few twinned ones, which are subjected to severe metamorphism as revealed by the bent twin lamellae, crushing and wavy extinction, along with myrmeketic and micropertthetic intergrowths. The twinned laths exhibit mostly very fine lamellae and are devoid of sub-individuals. The twins present in this group of charnockites come under the category of A- and C-twins as they mostly have the parallel twins dominating the normal twins. These facts clearly indicate that the rocks are products of metasomatic processes.



Some twinned plagioclases in charnockitic rocks. - 10.

SUMMARY AND CONCLUSIONS.

An attempt is made to understand the genesis of the charnockitic rocks of the Eastern Ghats from the study of twinning of their plagioclases. It is suggested that the basic members are of igneous origin whereas the intermediate and acid varieties are the products of metasomatic and metamorphic processes involving addition of foreign rock material and its incorporation by the parent basic charnockite.

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The authors are grateful to Prof. C. Mahadevan for his keen interest in the work.

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NOTE ON THE FRAGMENTATION OF CONICAL 'LINERS' AND ITS RELATION TO THE THEORY OF 'SHAPED-CHARGE'

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1. INTRODUCTION.

The present note deals with some experimental work on inverted conical liners. The results have some interest in relation to the theory of 'Shaped-Charge'. The experimental arrangement corresponds to the reversal of the usual conical liner in a 'Shaped-Charge' equipment, that is, the vertex of the cone points (not towards but) away from the charge. The technique of base detonation of the high explosive filling is the same. On firing, the liner disintegrates into fragments. The fragmentation-pattern is recorded on a mild steel 'witness-plate'.

2. EXPERIMENTAL WORK.

Conical 'liners' of angle 45° , outside base diameter 3.0 in. and thickness 0.096 in. were machined from rods of mild steel. The conical liner was soldered at one end of a gas pipe of 3.0 in. internal diameter and $\frac{1}{4}$ in. wall thickness. High explosive, which was a mixture of trinitrotoluene (T.N.T.) and trinitrophenylmethyl-nitramine (tetryl) in the ratio of 70 ; 30, was cast (poured hot and allowed to cool). The weight of the high explosive filling was $1\frac{1}{2}$ lbs. Care was taken to avoid piping during casting. A guncotton primer (weight 1 oz.) was used as a booster. It was primed by a detonator No. 27 to which 2 feet of safety fuse was crimped. A mild steel plate (0.25 in. thick) was used as a 'witness-plate'. The lay-out of the equipment for firing is shown in Fig. 1.

On firing the liner broke into fragments which struck the 'witness-plate' and produced on it a fragmentation-pattern. A typical fragmentation-pattern, which consists of a ring, is shown in Fig. 2. Obviously, the outer and the inner circumferences of the ring are due to the impact of fragments from the metal near the base and the apex of the liner respectively. The metal in the ring is scooped out in a radial direction and each radial trough has got a scaly appearance. The impressions made on the target by the fragments from the base are deeper than those made by the fragments from the apex of the conical liner. It will be seen from Fig. 2 that the outer diameter can be accurately measured but the measurements of the inner diameter are comparatively approximate. A high degree of reproducibility for the outer diameter is obtained when equipments of the same dimensions are loaded and detonated in the same way. Let $2N$ and $2M$ represent the outside and the inside diameters of the ring respectively. Let S represent the vertical distance between the base of the liner and the 'witness-plate'. The values of S , $2N$ and $2M$ are given in Table I.

3. DISCUSSIONS.

In the experiments described above a plane detonation wave travelling along the axis of the equipment sweeps from the base to the apex of the conical liner. It exerts enormous pressures on the surface of the liner. Under these conditions the strength of the liner may be assumed to be negligible and the metal may be

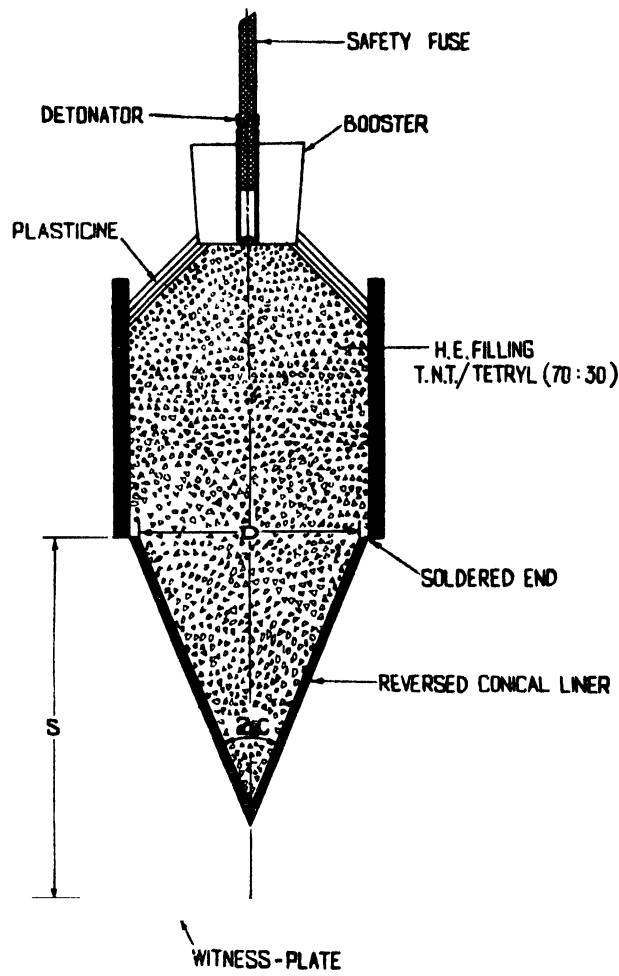


FIG. 1. Lay-out of the equipment with a reversed conical liner.

TABLE I.
Dimensions of the fragmentation-pattern and calculated values of angle δ .

No. of firings	Distance of the base of the liner from the 'witness-plate' S (inch)	Dimensions of fragmentation-pattern		Calculated angle	
		Outer dia. $2N$ (inch)	Inner dia. $2M$ (inch)	δ_0 (deg.)	δ_1 (deg.)
1	4.5	17.3	4.5	9.3	4.2
2	4.5	17.4	4.8	9.1	2.7
3	4.5	17.0	4.3	9.9	5.2
4	4.5	17.2	4.5	9.5	4.2
5	4.5	17.1	4.3	9.7	5.2
6	4.5	17.3	4.4	9.3	4.7
7	4.5	17.2	4.3	9.5	5.2
8	4.5	17.5	4.6	9.0	3.7
Mean				9.4	4.4



FIG. 2. Typical fragmentation pattern on a mild steel 'witness-plate'.

r regarded as almost a perfect fluid. Let U_d represent the velocity of detonation which is assumed to be constant from the base to the apex of the liner (see, for instance, Pugh *et al.*, 1952). Let 2α represent the angle of the conical liner. Suppose that the detonation wave at time t_0 is at the base of the cone and has arrived at C at time t (Fig. 3). Consider a system of co-ordinates moving with

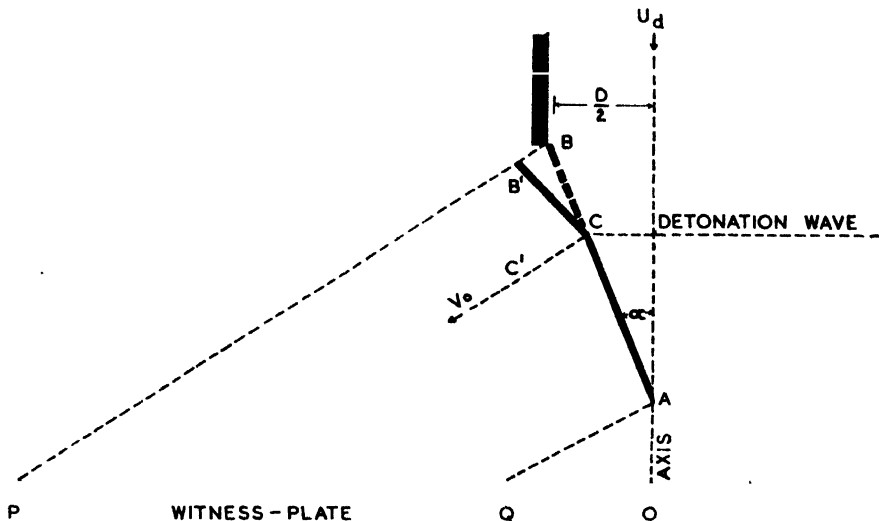


FIG. 3. Geometrical representation of the formation of fragmentation-pattern. BA is the half of the conical liner. The collapsing element moves with velocity V_0 .

constant velocity U_d sec \propto along the direction A to B : in this system detonation wave is stationary at C but the liner is moving. Since the pressure of the detonation wave is assumed to be everywhere normal to the liner, it results in only changing the direction, and not the magnitude, of the liner velocity. Before entering the detonation wave at C the liner is moving along AC . Let it move along CB' after its passage across the detonation wave. If V_0 is the velocity of the collapsing liner-element (at C) in the stationary system of co-ordinates, it follows that V_0 bisects the angle ACB' . Denoting the angle ACC' by θ , we have

$$V_0 = 2U_d \sec \alpha \cos \theta.$$

If δ represents the angle between the direction of V_0 and the perpendicular to the original liner surface, then we have

$$\delta = \frac{\pi}{2} - \theta$$

and

$$V_0 = 2U_d \sec \propto \sin \delta \quad \dots \quad \dots \quad \dots \quad (1)$$

The fragments strike the witness-plate and form a fragmentation-pattern. In Fig. 3 the annular thickness of the pattern is indicated by PQ . If δ_0 denotes the value of δ for the liner-element near the base of the liner and δ_1 the value of δ for the element near the apex, we note from the geometry of the arrangement (Fig. 3)

$$\begin{aligned} \delta_0 &= \frac{\pi}{2} - \alpha - \tan^{-1} \frac{2N-D}{2S} \\ \delta_1 &= \frac{\pi}{2} - \alpha - \tan^{-1} \frac{2M}{2S-D \cot \alpha} \end{aligned} \quad \left. \begin{array}{l} \vdots \\ \vdots \\ \vdots \end{array} \right\} \quad (2)$$

where D is the inner base diameter of the conical liner. The calculated values of δ_0 and δ_1 are tabulated in Table I.

Assuming U_d to be 7,025 m./sec. and substituting the values of U_d and δ in equation (1), we have

$$V_0 = 1.2 \times 10^3 \text{ m./sec. (apex of liner)}$$

$$V_0 = 2.5 \times 10^3 \text{ m./sec. (base of liner)}$$

In a 'Shaped-Charge' the detonation wave travels from the apex to the base of the liner, whereas in our case it travels from the base to the apex. All the same as is clear from the foregoing discussion, we should expect the collapse-velocity V_0 to be the same in both the cases. It is thus interesting to observe that the values of V_0 given above agree (to order of magnitude) with those of Eichelberger and Pugh (1952) (Fig. 10 of their paper). Thus the experiments on the reversed liner here described may be regarded as providing some evidence for the decrease in collapse-velocity as we go from the base to the apex of the reversed liner (that is, apex to base for 'Shaped-Charge' liner).

The authors are grateful to the Director-General of Ordnance Factories, Ministry of Defence, and the Director of Technical Development, Army Headquarters, for facilities provided in connection with the above work.

ABSTRACT.

Recently Pugh *et al.* (1952) have explained the formation of high-velocity 'Munroe' jets on the assumption of a variable, instead of a constant, collapse-velocity for the walls of the conical liner. In this note the fragmentation of an 'inverted' conical liner is considered, and the possible bearing of the results on Pugh's theory is discussed.

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THE PROBLEM OF FRAUNHOFER SCATTERING BY AN OPTICALLY CONTINUOUS TRANSPARENT AND THREE-DIMENSIONAL SCREEN AND ITS POSSIBLE APPLICATIONS

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INTRODUCTION.

Laue (1913) first calculated the intensity distribution of Fraunhofer scattering by a three-dimensional transparent medium. Later on his work gave birth to the highly important subject of X-ray Crystallography.

In that work the medium was considered as a three-dimensional crossed grating in space and the problem was considered thus, 'If it is possible to construct mechanically a crossed grating in space, what would be the nature of the Fraunhofer pattern if light rays are made to pass through such a transparent medium?' That was solved by Laue, and was applied to a crystal lattice.

A crystal lattice is not a continuous medium. In this paper the problem of Fraunhofer scattering by a continuous transparent medium has been solved and its possible application has been discussed. The expression for the distribution of intensity has been mathematically deduced.

PHYSICAL IDEAS.

The phase difference between the rays scattered by two neighbouring points is given by

$$\Phi \simeq \frac{4\pi}{\lambda_{\omega}} d \sin \frac{\epsilon}{2} \quad \dots \quad (1)$$

where Φ = the phase difference
 d = the distance between the two neighbouring points
 λ_{ω} = the wavelength of radiation
 and ϵ = the angle of scattering.

The absolute value of the phase difference entirely depends upon the variables λ_{ω} , d and ϵ . If d is very small in comparison to λ_{ω} , the expression of phase difference in (1) will be negligible even if ϵ is not small.

Now, if the entire medium be imagined to be an aggregation of indefinitely small volumes within which the phase change from the scatterers will be accordingly small, there is fair justification in considering the entire medium as optically continuous for all problems of coherent scattering.

THREE-DIMENSIONAL FRAUNHOFER SCATTERING PHENOMENA.

General Treatment.

Proceeding in the usual way of investigating the Fraunhofer class of diffraction (vide Drude, *Theory of Optics*, p. 185) we may put

$$I = A^2(C^2 + S^2) \quad \dots \quad (2)$$

where

$$C = \int \cos (\lambda x + \mu y + \nu z) d\tau$$

$$S = \int \sin (\lambda x + \mu y + \nu z) d\tau$$

and

$$\lambda = \frac{2\pi}{\lambda_{\omega}} (\alpha_1 + \alpha_0), \mu = \frac{2\pi}{\lambda_{\omega}} (\beta_1 + \beta_0)$$

$$\nu = \frac{2\pi}{\lambda_{\omega}} (\gamma_1 + \gamma_0)$$

λ_{ω} being the wavelength of radiation, $\alpha_1, \beta_1, \gamma_1$ being the direction cosines of the scattered ray and A is given by

$$I_0 = A^2 \tau^2 \quad \dots \quad (3)$$

where I_0 is the incident intensity and τ the volume of the scatterer. Therefore, the expression of intensity for three-dimensional Fraunhofer scattering becomes

$$\frac{I}{I_0} = \frac{1}{\tau^2} (C^2 + S^2) \quad \dots \quad (4)$$

DIFFRACTION BY SPHERICAL PARTICLES.

Preliminary Assumptions.

Following assumptions have been made for the sake of simplicity:—

- (1) The incident ray is parallel and opposite to the directions of z -axis.
- (2) The origin has been taken at the centre of the sphere and spherical polar system of co-ordinates has been introduced.
- (3) Refractive index has been assumed to be unity.

In spherical polar system, therefore, the following relationship holds:—

$$(i) \quad \begin{cases} \alpha_1 = \beta_1 = 0, \gamma_1 = \cos \pi \\ \alpha_0 = \sin \epsilon \cos \eta, \beta_0 = \sin \epsilon \sin \eta \text{ and } \gamma_0 = \cos \epsilon \end{cases}$$

where $\alpha_1, \beta_1, \gamma_1$ = direction cosine of the incident ray.

$\alpha_0, \beta_0, \gamma_0$ = direction cosine of the scattered ray.

ϵ = the angle which the scattered ray makes with z -axis, i.e., the angle of scattering.

η = the angle which the projection of the scattered ray on the xy -plane makes with x -axis.

$$(ii) \quad \begin{cases} \lambda = \frac{2\pi}{\lambda_{\omega}} \sin \epsilon \cos \eta = p \cos \eta \\ \mu = \frac{2\pi}{\lambda_{\omega}} \sin \epsilon \sin \eta = p \sin \eta \\ \nu = \frac{2\pi}{\lambda_{\omega}} (\cos \pi + \cos \epsilon) \end{cases}$$

where

$$p = \frac{2\pi}{\lambda_{\omega}} \sin \epsilon$$

(iii) In the intensity equation (4) $S = 0$. Then (4) becomes

$$\frac{I}{I_0} = \frac{C^2}{r^2} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (5)$$

$$\begin{aligned} \text{(iv)} \quad x &= r \sin \theta \cos \phi \\ y &= r \sin \theta \sin \phi \\ z &= r \cos \theta \\ d\tau &= r^2 \sin \theta dr d\theta d\phi. \end{aligned}$$

$$\begin{aligned} C &= \int_0^R \int_0^\pi \int_0^{2\pi} r^2 \sin \theta dr d\theta d\phi \cos r \{ p \sin \theta \cos (\phi - \eta) + \nu \cos \theta \} d\phi \\ &= \int_0^R \int_0^\pi r^2 \sin \theta dr d\theta \int_0^{2\pi} \cos r \{ p \sin \theta \cos (\phi - \eta) + \nu \cos \theta \} d\phi \\ &= \int_0^R \int_0^\pi r^2 \sin \theta dr d\theta \int_{-\eta}^{2\pi-\eta} \cos r \{ p \sin \theta \cos \phi' + \nu \cos \theta \} d\phi' \end{aligned}$$

where

$$\phi' = (\phi - \eta)$$

THE INTEGRAL IN ϕ' .

$$\begin{aligned} &= \int_{-\eta}^{2\pi-\eta} \cos r \{ p \sin \theta \cos \phi' + \nu \cos \theta \} d\phi' \\ &= \text{Real Part in} \\ &\quad e^{ir\nu \cos \theta} \int_{-\eta}^{2\pi-\eta} e^{irp \sin \theta \cos \phi'} d\phi' \quad \dots \quad \dots \quad \dots \quad \dots \quad (6) \\ &= e^{ir\nu \cos \theta} \int_{-\eta}^{2\pi-\eta} \left\{ 1 + irp \sin \theta \cos \phi' + \frac{(irp \sin \theta \cos \phi')^2}{2!} + \dots \right\} d\phi' \end{aligned}$$

Now

$$\begin{aligned} \int_{-\eta}^{2\pi-\eta} \cos \phi' d\phi' &= 0 & \int_{-\eta}^{2\pi-\eta} \cos^2 \phi' d\phi' &= 2\pi \cdot \frac{1}{2} \\ \int_{-\eta}^{2\pi-\eta} \cos^3 \phi' d\phi' &= 0 & \int_{-\eta}^{2\pi-\eta} \cos^4 \phi' d\phi' &= 2\pi \cdot \frac{3}{8} \\ &\dots & &\dots \end{aligned}$$

The odd powers cancel and consequently

$$\int_{-\eta}^{2\pi-\eta} \cos^{2m} \phi' d\phi' = \frac{(2m-1)(2m-3) \dots 3 \cdot 1}{2m(2m-2) \dots 4 \cdot 2} \cdot 2\pi$$

Therefore, the integral in ϕ'

$$\begin{aligned} &= \cos (r\nu \cos \theta) 2\pi \left\{ 1 - \frac{r^2 p^2 \sin^2 \theta}{2!} \cdot \frac{1}{2} + \frac{r^4 p^4 \sin^4 \theta}{4!} \cdot \frac{3}{8} \dots \right. \\ &\quad \left. (-1)^m \frac{(2m-1)(2m-3) \dots 3 \cdot 1}{2m(2m-2) \dots 4 \cdot 2} \cdot \frac{p^{2m} r^{2m}}{2m!} \sin^{2m} \theta + \dots \right\} \end{aligned}$$

THE INTEGRAL IN θ .

$$\begin{aligned}
&= \int_0^\pi \left[2\pi \sin \theta \left(1 - \frac{r^2 \nu^2 \cos^2 \theta}{2!} + \frac{r^4 \nu^4 \cos^4 \theta}{4!} - \dots (-1)^n \frac{r^{2n} \nu^{2n} \cos^{2n} \theta}{(2n)!} + \dots \right) \right. \\
&\quad \times \left\{ 1 - \frac{r^2 p^2 \sin^2 \theta}{2!} \cdot \frac{1}{2} + \frac{r^4 p^4 \sin^4 \theta}{4!} \cdot \frac{1}{8} - \dots \right. \\
&\quad \left. \left. (-1)^m \frac{(2m-1)(2m-3) \dots 3 \cdot 1}{2m(2m-2) \dots 4 \cdot 2} \times \frac{p^{2m} r^{2m} \sin^{2m} \theta}{(2m)!} + \dots \right\} \right] d\theta \\
&= \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} (-1)^{m+n} \frac{(2m-1)(2m-3) \dots 3 \cdot 1}{(2m)! (2n)! 2m(2m-2) \dots 4 \cdot 2} \\
&\quad \times r^{2m+2n} 2\pi \cdot p^{2m} \nu^{2n} \int_0^\pi \sin^{2m+1} \theta \cos^{2n} \theta d\theta \\
&= \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} (-1)^{m+n} \frac{2\pi p^{2m} \nu^{2n}}{(2n)! (2^m \cdot m!)^2} r^{2m+2n} \int_0^\pi \sin^{2m+1} \theta \cos^{2n} \theta d\theta \\
&= \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} (-1)^{m+n} \frac{8\pi p^{2m} \nu^{2n} (m+n+1)!}{m! n! (2m+2n+2)!} r^{2m+2n}
\end{aligned}$$

THE INTEGRAL IN r .

$$\begin{aligned}
&= \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} (-1)^{m+n} \frac{8\pi p^{2m} \nu^{2n} (m+n+1)!}{m! n! (2m+2n+2)!} \int_0^R r^{2m+2n+2} dr \\
&= \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} (-1)^{m+n} \frac{8\pi p^{2m} \nu^{2n} (m+n+1)!}{m! n! (2m+2n+3)!} R^{2m+2n+3}
\end{aligned}$$

Therefore

$$C = 8\pi R^3 \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} (-1)^{m+n} \frac{(2\pi)^{2(m+n)} (m+n+1)! \sin^{2m} \epsilon (\cos \epsilon - 1)^{2n}}{m! n! (2m+2n+3)!} \left(\frac{R}{\lambda} \right)^{2(m+n)} \quad \dots \quad (6)$$

Therefore, from (5) the expression for intensity is given by

$$\frac{I}{I_0} = 36 \left| \sum \sum (-1)^{m+n} \frac{(2\pi)^{2(m+n)} (m+n+1)! \sin^{2m} \epsilon (\cos \epsilon - 1)^{2n}}{m! n! (2m+2n+3)!} \cdot \left(\frac{R}{\lambda} \right)^{2(m+n)} \right|^2 \quad \dots \quad (7)$$

This is the intensity equation for a medium whose refractive index with respect to its outside medium is always equal to unity.

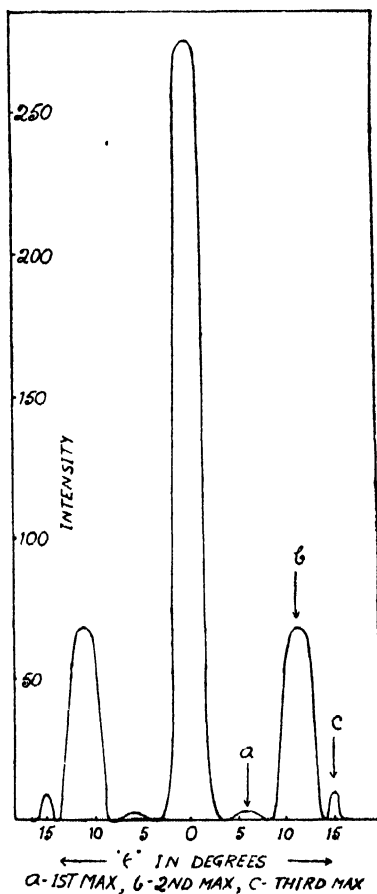
The expression within the $\left| \right|$ bracket is a convergent series, but of oscillatory nature between certain limits of the scattering angle ϵ , depending upon the size of medium R . Therefore, between such angular limits the maxima and minima of intensity pattern will occur. The larger the values of R , the more will the position

of maxima be shifted towards smaller angles. The values of I/I_0 up to 17 degree is given in the following tables, for the value of $\frac{R}{\lambda} = 10$.

TABLE.

ϵ in degrees	$\frac{I}{I_0} \times 36$	ϵ in degrees	$\frac{I}{I_0} \times 36$
0	279×10^{-4}	10	54.3×10^{-4}
1	19.6×10^{-4}	11	69.9×10^{-4}
2	17×10^{-4}	12	0.09×10^{-4}
3	$.9 \times 10^{-4}$	13	0.006×10^{-4}
4	$.5 \times 10^{-4}$	14	0.23×10^{-4}
5	1.4×10^{-4}	15	10.82×10^{-4}
6	1.2×10^{-4}	16	1.06×10^{-4}
7	$.5 \times 10^{-4}$	17	0.67×10^{-4}
8	$.2 \times 10^{-4}$		
9	14×10^{-4}		

The corresponding intensity curve is given below.



PHYSICAL APPLICATIONS.

The general intensity (7) will always be applicable in all cases of physical phenomena of Fraunhofer scattering where the values of λ_ω , d and ϵ are so adjusted that the expression (1) is negligibly small.

APPLICATION IN THE CASE OF 'X-RAY SCATTERING'.

In the case of 'X-ray Scattering' the values of λ_ω and d are nearly of the same order of magnitude and the expression (1) will be negligible only when ϵ is small. Therefore, 'Low Angle Scattering' Phenomena naturally come under the scope of these deductions [Gupta (1952)].

If ϵ is small then ν of relationship (ii), given by $\nu = \frac{2\pi}{\lambda_\omega} (\cos \pi + \cos \epsilon)$, will be equal to zero.*

Then from equation (6) we get

$$G = \tau \sum_{m=0}^{\infty} (-1)^m \frac{3(2m+2)}{(2m+3)!} u^{2m}$$

where

$$\begin{aligned} pR &= u \\ R &= \text{the particle size} \\ &= \tau \left[1 - \frac{u^2}{2 \cdot 5} + \frac{u^4}{2 \cdot 4 \cdot 5 \cdot 7} - \dots \right] \\ \frac{I}{I_0} &= \left[1 - \frac{u^2}{5} + \left(\frac{u^2}{5} \right)^2 \frac{1}{2!} \cdot \frac{6}{7} - \dots \right] \end{aligned}$$

By making the value of the particle size sufficiently small † in (8) we can write—

$$I = I_0 e^{-\frac{u^2}{5}} (\text{approx.}) \quad \dots \quad (8)$$

So, Guinier's (1939) formula for Low Angle Scattering of X-ray is easily often experimentally verified by him.

ACKNOWLEDGEMENT.

The author is grateful to Prof. K. Banerjee for his kind interest and advice in the work.

* In the case of graphite indicated by copper K_α radiation $\epsilon = 6'$, $\cos 6' = 0.99999$. Therefore $\nu = -0.00001 \simeq 0$.

† When $R = 100 \text{ \AA}$, $\epsilon = 6' = 17 \times 10^{-4}$ radians, $\lambda_\omega = 1.5 \text{ \AA}$ for copper K_α radiation, we get

$$\begin{aligned} u &= \frac{2\pi}{\lambda_\omega} \epsilon R = \frac{10}{15} \\ \left(\frac{u^2}{5} \right)^2 \cdot \frac{1}{2!} &= \frac{1}{110} (\text{approx.}) \\ \frac{1}{7} \left(\frac{u^2}{5} \right)^2 \cdot \frac{1}{2!} &= \frac{1}{800} (\text{approx.}) \end{aligned}$$

Therefore, for particles of magnitude 100 \AA , we are making an error of 0.12 per cent. For particles of much lower dimensions the error is much smaller.

ABSTRACT.

The general problem of Fraunhofer scattering by a three-dimensional continuous and transparent medium has been mathematically solved and its physical application has been discussed. It is seen that at lower angles the general intensity equation is transformed into well-known Guinier's intensity equation of X-ray low angle scattering.

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SYNTHESIS OF UNSATURATED LONG CHAIN FATTY ACIDS

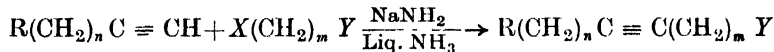
by R. SEN GUPTA,¹ A. GROLLMAN² and S. C. NIYOGY.¹

(Communicated by S. N. Bose, F.N.I.)

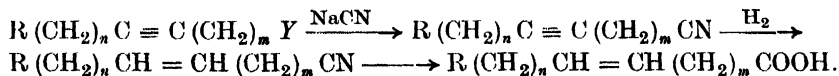
(Received November 24, 1952; read March 6, 1953.)

The identification of some of the component unsaturated acids in the liver oil of *Galeocedro tigrinus* had been successfully accomplished by the formation of *p*-phenyl phenacyl esters and the constitution of the acids had been determined by their oxidative degradation. Although these reactions leave very little doubt about the constitution of the acids, the most convincing proof would be the synthetic preparation of these acids and their comparison with those obtained from natural sources. Excellent methods had been developed within the last few years for the synthesis of long chain unsaturated acids by Ahmad and Strong (1948), Raphael and Sondheimer (1950), Leese and Raphael (1950), Ames and Bowman (1951). Mono-ethenoid acids had been synthesized by many of these authors and the di-ethenoid, linoleic acid had been synthesized by two different routes by Raphael and Sondheimer (1950) and also by Walbrosky, Davis and Howton (1951).

The method developed by Ahmad and Strong (*loc. cit.*) was based on the condensation of an acetylenic hydrocarbon with terminally substituted dihalogen derivatives of paraffins in presence of sodamide in liquid ammonia:



A limitation of the applicability of this method had been pointed out by Leese and Raphael (1950) and also by Taylor and Strong (1950). The solubility of the sodio derivative of the acetylenic hydrocarbon in liquid ammonia was found to diminish rapidly as the number of carbon atoms increased. It had been found that the reaction was successful when *n* lies between 3 and 10 (Henne and Gronlee, 1945). In the second stage of the synthesis, the halogen *Y* was replaced by —CN by the action of sodium cyanide in a suitable medium. Partial hydrogenation with Raney Nickel w-6 or palladium on calcium carbonate gave the corresponding ethylenic compound which was subsequently hydrolyzed to the acid by alkali.



In the present investigation the method outlined before was adopted finally, after some unsuccessful attempt to substitute a symmetrical disubstituted paraffin, $X(CH_2)_m X$ for the unsymmetrical one, as the preparation and purification of latter type of compounds were tedious. It was found that the reaction did not proceed smoothly and the expected product was very difficult to isolate in a state of purity.

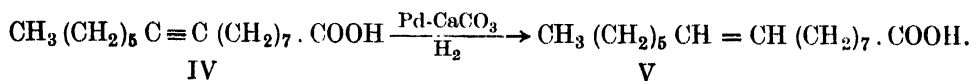
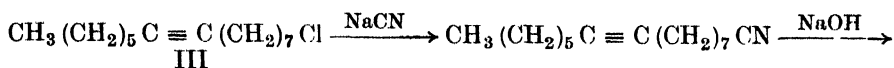
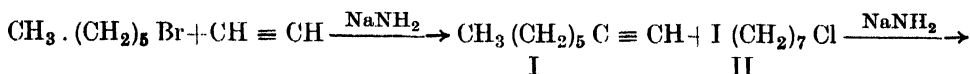
For the synthesis of C_{16} mono-ethenoid acid, which was considered to be palmitoleic acid, the necessary components were the following: (1) 1-octyne, (2) 1-chloro-7-iodo heptane. 1-Octyne was prepared by the method adopted by Ahmad,

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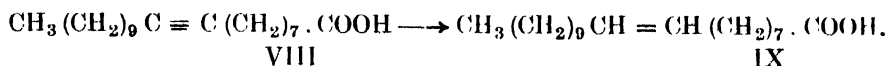
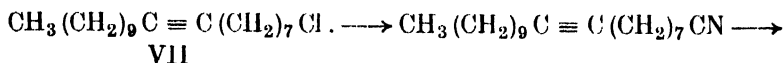
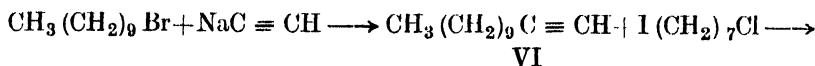
² South-Western Medical College, Dallas, Texas, U.S.A.

Bumpus and Strong (1948) from *n*-hexyl bromide and sodium acetylide; 1-chloro-7-iodo heptane was prepared by the following series of reactions:—

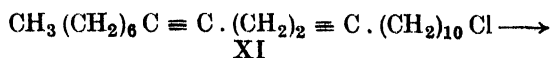
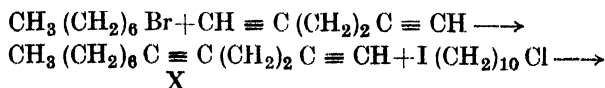
Piperidine \longrightarrow benzoyl piperidine \longrightarrow 1 : 5-bromo pentane \longrightarrow 1 : 5-dicyano pentane \longrightarrow pimelic acid \longrightarrow pimelic ester \longrightarrow heptandiol 1 : 7 \longrightarrow 1 : 7-dichloro heptane \longrightarrow 1-chloro-7-iodo heptane. The condensation of 1-octyne (I) with 1-chloro-7-iodo heptane (II) was carried out according to the method of Ahmad and Strong (*loc. cit.*) and the acetylenic chloride (III) was obtained in fairly good yield. The replacement of chlorine by $-\text{CN}$ was effected with sodium cyanide, and hydrolysis with caustic soda gave the acetylenic acid (IV). Partial hydrogenation with hydrogen in presence of palladium on calcium carbonate gave the acids (V) which had the same characteristics as that isolated from the liver oil of *Galeocedro tigrinus*.

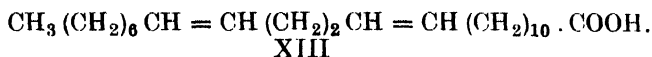
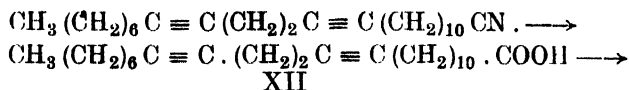


The synthesis of C_{20} -mono-ethenoid acid, Gadoleic acid, was carried out by the condensation of 1-bromo decane with sodium acetylide to give dodeca 1-yne (VI) which was then reacted with 1-chloro-7-iodo heptane. After the usual reactions, the acid was obtained as its ethyl ester (IX).



As stated before, the synthesis of di-ethenoid long chain fatty acid had been successfully accomplished very recently. Raphael and Sondheimer (1950) had described the synthesis of Undeca 1 : 7-diene 1-carboxylic acid by the condensation of octa 1 : 7-diyne with propyl iodide and carboxylation of the Gagnard complex with dry ice, followed by partial hydrogenation. In a later publication, the same authors had employed hexa 1 : 5-diyne (dipro-pargyl) and propyl iodide, followed by carboxylation and hydrogenation to give nona 1 : 7-diene 1-carboxylic acid. For the synthesis of linoleic acid, these workers had to adopt a slightly different method on account of the reactivity of the methylene group between the two unsaturated carbon atoms. Walborsky, Davis and Howton (1951) had also recently described the synthesis of linoleic acids based on the same method but with wide modifications. In view of these recent publications, the route to the synthesis of C_{24} di-ethenoid acid, which had been isolated and identified as described in the previous communication, was clearly indicated as detailed below:—





When this scheme was decided upon, there was some apprehension that trideca 1 : 6-diyne (X) might be sparingly soluble in liquid ammonia in view of the observations of Leese and Raphael (1950) and also of Taylor and Strong (1950). But fortunately the diacetylinic compound was found to be fairly soluble in liquid ammonia and the reaction proceeded without much difficulty.

EXPERIMENTAL.

Octa-1-yne (I).—Sodium (4.8 g.) was added in small pieces to liquid ammonia (200 c.c.), through which a stream of acetylene was passed with gentle mechanical stirring (-30°C). The rate of addition of sodium was so adjusted that the blue colour that developed, disappeared before the next addition of sodium. The current of acetylene was stopped immediately when the blue colour disappeared after the addition of the last portion of sodium, thus ensuring that no excess of acetylene was present. *n*-Hexyl bromide (40 g.) was gradually added to the reaction mixture in the course of 30 minutes and the whole agitated for 3 hours. The vessel was allowed to stand overnight when most of the ammonia had evaporated. It was treated very cautiously with ice-cold water, the organic portion taken up in ether, washed and dried over anhydrous magnesium sulphate. Removal of ether and distillation of the residue gave octa-1-yne, b.p. $123-26^\circ$, yield 53% (Ahmad, Bumpus and Strong, 1948).

1-Chloro-7-iodo heptane (II).—Heptandiol 1 : 7 (Dionneau, 1907), b.p. $170-75^\circ/25$ mm. was converted into 1 : 7-dichloro heptane by the action of thionyl chloride in presence of pyridine (Ahmad and Strong, 1948), b.p. $127-33^\circ/23$ mm. *n*, 1.4513. The dichloride (30 g.) in acetone (150 c.c.) was heated to boiling under reflux and treated with a molecular equivalent of sodium iodide in acetone (150 c.c.), in the course of 3 hours. The heating was continued for a further period of 4 hours and the solvent distilled off. The separated sodium chloride was filtered off and the organic portion taken up in ether, washed with water and dried over potassium carbonate. Repeated distillation through an efficient column gave 1-chloro-7-iodo heptane, b.p. $112-14^\circ/0.1$ mm. (17 g.). (Found:—I, 48.42; $\text{C}_7\text{H}_{14}\text{I}$ requires I, 48.1%.)

Sodamide.—Liquid ammonia (500 c.c.) was placed in a 3-necked flask and cooled with alcohol-dry ice. The flask was provided with a stirrer, a gas inlet tube and an efficient condenser. With slow stirring ferric nitrate (0.18 g.) and sodium (0.5 g.) were added to the liquid ammonia. A current of dry nitrogen was passed through the liquid until the blue colour was discharged, after which, sodium (5 g.) was added in small pieces. The reaction was allowed to proceed for about 30 minutes and sodium peroxide (0.3 g.) was added to the reaction mixture. The stirring was continued for 3 hours when a dull grey product was formed and the formation of sodamide was judged to be complete (compare Ahmad and Strong, 1948).

1-Chloro pentadeca 8-yne (III).—Octa 1-yne (25 g., 0.25 mol.) was added slowly with mechanical stirring over a period of 3 hours, to a suspension of sodamide prepared from sodium (5.5 g.) in liquid ammonia (500 c.c.) and the stirring continued for a further period of 4 hours (dry ice). 1-Chloro-7-iodo heptane (65 g., 0.25 mol.) was added to this reaction mixture during 4 hours and the whole stirred for another 6 hours. The vessel was then allowed to stand for 24 hours when most of the

ammonia had evaporated. The residue was cautiously treated with ice-cold water (250 c.c.) and the organic layer taken up in ether. The ethereal extract was washed with ice-cold water, dried over magnesium sulphate and the solvent distilled off. The residue was submitted to distillation. The first fraction (6 c.c.) was unchanged chloriodo heptane, b.p. 153–60°/30 mm. The second fraction was collected, b.p. 160–75°/28 mm. (25 c.c.). This was redistilled and the required compound was obtained in the fraction distilling between 130° and 132°/1 mm. n , 1.4523. (Found:—Cl, 14.41; $C_{16}H_{27}Cl$ requires Cl, 14.64%.)

Hexadec-9-ynoic acid (IV).—Sodium cyanide (12 g.) was dissolved in water (20 c.c.) and rectified spirit (100 c.c.) was added. To this solution, 1-chloro penta-deca 8-yne (20 g.) was added and the mixture treated under reflux for 24 hours. Caustic potash (20 g.) was next added to the mixture and the heating continued for a further period of 24 hours. The solvent was then distilled off, the residue treated with water, cooled and extracted with ether to remove unreacted starting material. The aqueous portion was acidified and the separated oil taken up in ether. After the usual washing and drying, the solvent was removed and the acid esterified with ethyl alcohol. The ester was extracted by the usual process and distilled. The main distilling between 110 and 115°/0.05 mm. (12 c.c.) was collected; n , 1.4589. (Found:—C, 77.03; H, 11.56; $C_{16}H_{32}O_2$ requires C, 77.14; H, 11.40%.)

Hexadec-9-enoic acid (V).—The acetylenic ester (8 g.) in ethyl acetate (80 c.c.) was stirred magnetically in an atmosphere of hydrogen in presence of palladium-calcium carbonate catalyst (0.4 g., 2% Pd) until one molecular equivalent of hydrogen had been taken up (647 c.c. at 762 mm.). The catalyst was filtered off and the solvent removed under vacuo. The residual oil was distilled, b.p. 130–32°/0.06 mm. n , 1.4491. (Sap. Eq. 177.8, I.V. 93.26, *p*-phenyl phenacyl ester, m.p. 89–90°. Dihydroxy derivative, m.p. 123–24°, Armstrong and Hilditch, 1925.)

Dodeca-1-yne (VI).—Decanol-1 was prepared by the method of Schultz (1909), b.p. 117–20°/18 mm. and was converted into 1-bromo decane, b.p. 110–12°/12 mm. n , 1.4637 (Kraft, 1884). The bromo compound was condensed with sodium acetylide in liquid ammonia by the method described before. Dodeca 1-yne was obtained in 53% yield, b.p. 95–97°/762 mm. (Kraft and Reuter, 1892).

1-Chloro nonodeca-8-yne (VII).—Dodeca 1-yne (42 g., 0.25 mol.) was added slowly to a suspension of sodamide (from sodium, 6 g.) in liquid ammonia (600 c.c.) cooled in alcohol-dry ice bath over a period of 6 hours with stirring. The stirring was continued for a further period of 4 hours and 1-chloro-7-iodo heptane (65 g., 0.25 mol.) was added in the course of 8 hours. The mixture was stirred for a further period of 6 hours and allowed to stand for 24 hours. After the evaporation of ammonia, the residue was treated with cold water and the organic portion taken up in ether. After removal of the solvent the residual liquid was distilled. Unchanged 1-chloro-7-iodo heptane (10 g.) was obtained in the fraction distilling between 145–50°/13 mm. The second portion of the distillate was collected at 180–85°/15 mm. Redistillation gave a product, b.p. 150–52°/0.025 mm., n , 1.4611. (Found:—Cl, 11.72; $C_{19}H_{35}Cl$ requires Cl, 11.89%.)

Eicos 9-ynoic acid (VIII).—To a solution of sodium cyanide (12 g.) in water 30 c.c. and rectified spirit (250 c.c.) 1-chloro monodeca-8-yne (60 g., 0.20 mol.) was added and heated under reflux for 24 hours. Almost the whole of organic chloride was converted into sodium chloride during this digestion. The liquid was treated with sodium hydroxide (20 g.) and heating continued for another 20 hours. The solvent was then removed under reduced pressure and the residue, after cooling, was treated with water and twice extracted with ether to remove unchanged starting materials. The aqueous phase was well cooled, acidified with dilute sulphuric acid (10%) and the organic part taken up by extraction with ether (thrice). After evaporation of the solvent, the residue was dissolved in aqueous caustic potash and twice extracted with ether to remove impurities. The aqueous solution was again acidified and the oil taken up in ether. The residue left on evaporation was

converted into ethyl ester by the usual method and the ester submitted to distillation. Yield 30 c.c., b.p. 133–36°/0.25 mm.; n_D , 1.4610. (Found:—C, 77.52; H, 10.43; $C_{22}H_{44}O_3$ requires C, 77.64; H, 10.3%.) Catalytic hydrogenation with platinum oxide gave a saturated acid, m.p. 75–76°, identical with the m.p. of arachidic acid.

Eicos 9-enoic acid (IX).—The acetylenic ester (5 g.) was hydrogenated in ethyl acetate solution (50 c.c.) with palladium-calcium carbonate catalyst (0.4 g., 2% Pd) at ordinary temperature until one molecular proportion of hydrogen had been absorbed (405 c.c. at 758 mm.). The catalyst was filtered off and the solvent removed under vacuo at ordinary temperature. The residual oil was distilled, b.p. 155–58°/0.1 mm. (Sap. Eq. 161.2, I.V. 74.6; n_D , 1.4576, *p*-phenyl phenacyl ester m.p. 64–65°.)

Hexa 1 : 5 diyne.—1 : 2 : 5 : 6-Tetrabromo hexane was prepared by the bromination of hexa 1 : 5-diene. The debromination of the tetrabromide was carried out by the method employed by Raphael and Sondheimer (1950) with soda-mide in liquid ammonia, b.p. 88–89°; n_D , 1.4384, yield 45%.

1-Bromo heptane.—Heptyl alcohol was prepared by the reduction of ethyl oenanthane with sodium in ethyl alcohol (Gysergem, 1906), b.p. 173–75°. 1-Bromo heptane was obtained by the action of red phosphorus and bromine on the alcohol (Bogert, 1903), b.p. 179–80°.

1-Chloro-10-iodo decane.—Ethyl ester of sebacic acid was reduced with sodium and alcohol to the diol which was isolated by the usual method. Yield 78%, b.p. 70–72° (compare Schuble, 1903). Dichloro decane-1 : 10 was obtained by the action of thionyl chloride on the diol in presence of pyridine (Ahmad, Bumpus and Strong, 1948), b.p. 110–12°/0.2 mm.; n_D , 1.4603. (Found:—Cl, 33.52; $C_{10}H_{20}Cl_2$ requires Cl, 33.65%.) The dichloride (42 g., 0.2 mol.) in acetone (200 c.c.) was mixed with a solution of sodium iodide (30 g., 0.2 mol.) in acetone (200 c.c.) and heated under reflux for 8 hours, with mechanical stirring. The solvent was then distilled off and the inorganic salts filtered off. The oil was washed with water and dried over potassium carbonate. Fractional distillation under vacuo gave the following fractions: (a) b.p. 108–10°/0.25 mm.—unchanged dichloride. (b) 22 g., b.p. 138–42°/0.2 mm. n_D , 1.4623. (Found:—Cl, 10.72; I, 41.72; $C_{10}H_{20}I_2$ requires Cl, 10.02; I, 41.98%.)

Tridec 1 : 5-diyne (X).—An ethereal solution of dipropargyl (15 g., 0.2 mol.) in dry ether (100 c.c.) was cooled for 1 hour (dry ice-alcohol). The condensing agent sodamide was prepared from sodium (4.6 g.) in liquid ammonia with ferric nitrate catalyst. The ethereal solution of dipropargyl was added to the suspension of sodamide with cooling and stirring during the course of 1 hour and the stirring was continued for a further period of 2 hours. Heptyl bromide (35 g., 0.2 mol.) in ether (100 c.c.) was added dropwise to the mixture (1½ hours) and the reaction allowed to proceed for 8 hours. Ammonium chloride (20 g.) was added and the ammonia allowed to evaporate slowly by keeping the vessel overnight without cooling. The residue was treated cautiously with ice-cold water, the ethereal layer separated, washed with water, dilute sulphuric acid and sodium bicarbonate. The solvent was removed and the residual liquid distilled. The required acetylenic compound was obtained as a mobile liquid, b.p. 102–4°/12 mm.; n_D , 1.4619. (Found:—C, 88.63; H, 11.48; $C_{13}H_{20}$ requires C, 88.71; H, 11.36%.)

1-Chloro tricos 11 : 15-diyne (XI).—Sodamide was prepared from sodium (4 g.) in liquid ammonia (1,000 c.c.) by the method of Ahmad and Strong (1948). To the suspension of sodamide, tridec 1 : 5-diyne (18 g., 0.2 mol.) was added slowly over a period of 3 hours with stirring and the stirring continued for another period of 3 hours. 1-Chloro-10-iodo decane (60 g., 0.2 mol.) was added slowly during 6 hours and the reaction allowed to proceed for a further period of 6 hours. The vessel was allowed to stand for 24 hours for the evaporation of ammonia and the residue treated with ice-cold water (200 c.c.). The organic portion was taken up in ether,

washed with ice-cold water and dried over magnesium sulphate. The residue, after removal of solvent, distilled at b.p. 190–95°/0.2 mm. Redistillation gave a distillate, b.p. 192–95°/0.25 mm.; n_D , 1.4683. (Found:—Cl, 10.32; $C_{23}H_{39}Cl$ requires Cl, 10.28%.)

Tetracos 12 : 16-diynoic acid (XII).—Sodium cyanide (10 g., 0.2 mol.) was dissolved in water (10 c.c.) and rectified spirit (120 c.c.) was added to the solution. The liquid was heated to boiling under reflux and 1-chloro tricos 11 : 15-diyne (36 g., 0.1 mol.) was added gradually from a dropping funnel. The refluxing was continued for about 28 hours till the replacement of chlorine by cyanogen group was complete.

Caustic soda (10 g.) was next added and refluxed for 24 hours to complete the hydrolysis. The solvent was then distilled off under reduced pressure and the residue treated with cold water. The alkaline liquid was extracted with ether to remove unchanged starting material and after removal of the extracting liquid, the aqueous solution was well cooled and acidified with cold dilute sulphuric acid. The separated pasty mass was taken up in ether, washed with water and dried over magnesium sulphate. Evaporation of the solvent left 25 g. of a viscid oil which was immediately converted into ethyl ester. The ester was distilled. Yield 15 g., b.p. 152–55°/0.3 mm.; n_D , 1.4712. (Found:—C, 80.32; H, 11.52; $C_{26}H_{44}O_2$ requires C, 80.41; H, 11.32%.) Catalytic hydrogenation in presence of platinum gave a saturated acid, m.p. 80–81°, eq. wt. 367.3, identical with the m.p. and eq. wt. of lignoceric acid (Keeling, 1888).

Tetracos 12 : 16-dienoic acid (XIII).—The diacetynilic ester (5 g.) in ethyl acetate (25 c.c.) was magnetically stirred with hydrogen in presence of palladium-calcium carbonate catalyst (0.2 g., 2% Pd) until two molecular proportion of hydrogen (575 c.c. at 21°/762 mm.) had been absorbed. The operation was immediately stopped, the catalyst filtered off and the solvent removed under vacuo (25 mm.). The residual liquid was distilled, b.p. 162–65°/0.2 mm. D_4 , 1.4698, I.V. 129.3, *p*-phenyl phenacyl ester m.p. 57–58°.

ABSTRACT.

The paper describes the synthesis of the unsaturated fatty acid mentioned below:—

- (1) Hexadec 9-enoic acid.
- (2) Eicos 9-enoic acid.
- (3) Tetracos 12 : 16 dionoic acid.

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INVESTIGATIONS ON THE UNSATURATED ACIDS OF THE LIVER OIL OF *GALEOCEDRO TIGRINUS*

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INTRODUCTION.

In a recent publication, Grollman (1943, 1945) had shown that the administration of certain fish liver oils lowered the blood pressure of animals with experimentally induced hypertension. It was also found that molecular distillation of some fish oils gave certain fractions which were biologically active while others were inactive. Treatment with 100% hydrogen peroxide was found to enhance the original activity of the fish oils. But unfortunately the chemical nature of the active constituent of fish oils was not established.

MATERIAL AND METHOD.

In the present investigation, authentic samples of Indian shark liver oils supplied by the Government Oil Factory, Calicut, Madras, were employed. Several samples of shark liver oils of Indian origin were submitted to a preliminary test on rats with artificially induced hypertension and only one sample from *Galeocedro tigrinus* was found to be active (5 g. per rat, average body weight 300-350 g.). The results obtained relate to this particular variety of shark liver oil.

The first part of the work was concerned with the separation of the constituents of the oil, viz. unsaturated hydrocarbons, vitamin, etc. saturated and unsaturated fatty acids. A sample of the oil was saponified by the usual method with alcoholic caustic potash and after distilling off the alcohol, the residual soap was taken up in water and completely extracted with petroleum ether to take up the unsaturated hydrocarbons, vitamins, etc. After removal of the solvent, residue submitted to bio-assay on hypertensive rats showed no hypotensive action. Another portion of the same residue was brominated in ether and after removal of a pale yellow solid (supposed to be bromine addition product of the unsaturated hydrocarbons), the residual oil showed no activity on our hypertensive rats. These two preliminary observations were sufficient indications that the active constituent of the fish oil was not present in the unsaponifiable fraction and therefore the unsaturated hydrocarbons, vitamins, etc. could not be the hypotensive agent.

The separation of the saturated from the unsaturated acids was not considered to be difficult. There are several well-known methods for this purpose.

1. Lead salt alcohol method of Hilditch.
2. Lithium salt-acetone method of Tsujimoto (1920).
3. Low temperature crystallisation of Baudart (1943).
4. Mercuric acetate method of Bertram (1928).

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On account of non-availability of dry ice and necessary chemicals, the method of Hilditch was finally decided upon. A difficulty was, however, encountered which could not be surmounted. Due to prevailing high temperature, a part of the lead salt of the saturated fatty acid went into solution and could not be removed by repetition of the process. The saturated and unsaturated fatty acids, obtained by the decomposition of the lead salts by the usual methods, were submitted to bio-assay on hypertensive rats and only the unsaturated acids were found to be active (3.5 g. per rat, body weight 300–350 g.). Subsequent work was concentrated on the unsaturated acids.

For the preparation of the esters of the unsaturated acids, ethanol had to be substituted for methanol on account of the prohibitive price of the latter solvent. After the esterification was complete, the mixture was poured into ice-cold brine and the ester layer separated. But attempts to extract the esters in the aqueous phase with ether were abandoned after a few trials. It seemed that a portion of the ester was thus lost in the aqueous liquid and was not recovered. The ester layer was taken up in ether and after the usual washings with water, dilute sodium bicarbonate and water, was dried over anhydrous magnesium sulphate. After removing the solvent, the esters were carefully dried by heating on an oil bath at 180° under 35 mm. and then submitted to distillation in a 500 c.c. Willstätter flask. The following fractions were collected:—

	R.P.	Pressure.
Fraction I	125–40°	0.05 mm.
Fraction II	140–60°	0.06 mm.
Fraction III	160–72°	0.07 mm.

These three fractions were tested on hypertensive rats and Fractions I and III were found to be active (2.5 g. and 1.5 g. per rat). All the three fractions were then redistilled and distillates on a range of 5° to 6° were collected.

Original distillate.	Fraction No.	Boiling point.	Pressure.
125–40° ..	I _A	–120°	0.05 mm.
	I _B	120–24°	0.06 mm.
	I _C	124–30°	0.06 mm.
	I _D	130–36°	0.065 mm.
140–60° ..	II _A	140–45°	0.05 mm.
	II _B	145–49°	0.05 mm.
	II _C	149–56°	0.05 mm.
160–72° ..	III _A	157–62°	0.25 mm.
	III _B	162–70°	0.30 mm.

Of these nine fractions, only fraction I_D (b.p. 130–36°/0.06 mm.) and fraction III_B (b.p. 162–70°/0.3 mm.) were found to be biologically active in our experiments, the lowest dose being 0.5 g. for III_B and 1.5 g. for I_D per rat of average body weight 300–350 g.

It would be apparent from the analytical data for these different fractions as given in the experimental part, that the separation of the unsaturated acids, even by this high vacuum distillation, had not been satisfactory. The low iodine values of fractions I_A-I_C indicated the presence of saturated fatty acids, which had been referred to in the foregoing discussion. However, the main constituent of fractions I_A-I_D appeared to be a hexadeca monoethelynic acid. By catalytic hydrogenation with platinum catalyst at ordinary temperature, palmitic acid was obtained and the unsaturated acid was definitely identified as palmitoleic acid by oxidative cleavage also by the formation of solid derivative. Similarly fractions II_A-II_C appeared to be mixtures of octadeca acids with one, two or three double bonds. The identification of these acids had also been successfully accomplished by methods described later on. Fraction III_A was found to consist of a C_{20} acid with one double bond and was identified as Gadoleic acid, while the last fraction III_B was found to consist mainly of tetracosa diethynelic acid, the constitution of which had also been definitely established.

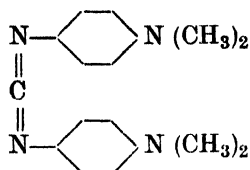
The identification of the individual acids in the different fractions was a difficult problem. In spite of the extensive investigations that had been carried out on the constitution of fats and oils, very few instances were recorded where chemical methods had been employed to isolate the individual fatty acids as crystalline derivatives and to identify these by chemical and physical methods. It was well known that derivatives usually recommended for the identification of fatty acids were of no use, as with these higher numbers of fatty acids these derivatives were usually liquid at ordinary temperatures. The following types of derivatives had been prepared from the unsaturated acids of the type described before:—

- (1) *s*-Benzyl thiourea salt.
- (2) *p*-Bromo phenacyl ester.
- (3) *p*-Phenyl phenacyl ester (Drake and Brontsky, 1930).
- (4) Bis- (*p*-dimethylamino phenyl) urea derivative (Zetzsche and collaborators (1938, 1939); Brausch and Ulasoy (1946)).

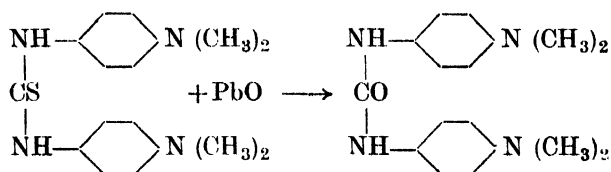
Our attempts to prepare crystalline derivatives by the first two methods were unsuccessful, the products being low melting solids or mixtures, which could not be separated by crystallisation. Employing *p*-phenyl phenacyl bromide (Drake and Brontsky, 1930), crystalline derivatives, mixed with low melting solids, were obtained from each fraction. In some cases, two substances of different m.p. had been obtained from a particular fraction, the analytical data being the same. These appeared to us to be isomers as similar isomerism had been observed by Behrman and Thomas (1951) who had isolated both oleic acid and elaidic acid in their synthetic product.

The preparation of bis- (*p*-dimethylamino phenyl) urea derivatives of the fatty acids gave rise to some difficulty owing to some misleading data in the literature. Brausch and Ulasoy (1945) stated that they had employed bis- (*p*-dimethylamino phenyl) thiourea, m.p. 86–89° for preparing the derivatives in ether solution. The compound had been prepared by Baur (1877), the m.p. of the compound being 186–87°. This was confirmed in the course of this work and the recorded m.p. of Brausch and Ulasoy was considered to be a typographical error. But the solubility of the compound in ether was negligible whereas Brausch and Ulasoy had stated that the solubility in ether was 6.3%; again the analytical data published by Brausch and Ulasoy for the derivative of the fatty acids showed that the substance did not contain any sulphur. The attempts made in the course of this work to bring about the condensation of the thiourea compound, in saturated ether solution, with the fatty acids were unsuccessful, the unchanged thiourea compound being isolated in every case. When bis- (*p*-dimethylamino phenyl) urea, m.p.

252° (Binde, 1877) and m.p. 246° (Michler and Zimmerman, 1879), was substituted for the thiourea compound, the condensation did not take place, the solubility of the urea compound in ether being about 1 mg./100 c.c. After these unsuccessful attempts, we communicated with Dr. Brausch and also Dr. Zetzsche. Dr. Brausch was kind enough to point out that the substance employed by him for the condensation with the fatty acids was not bis- (*p*-dimethylamino phenyl) thiourea but bis- (*p*-dimethylamino phenyl) -carbon di-imid

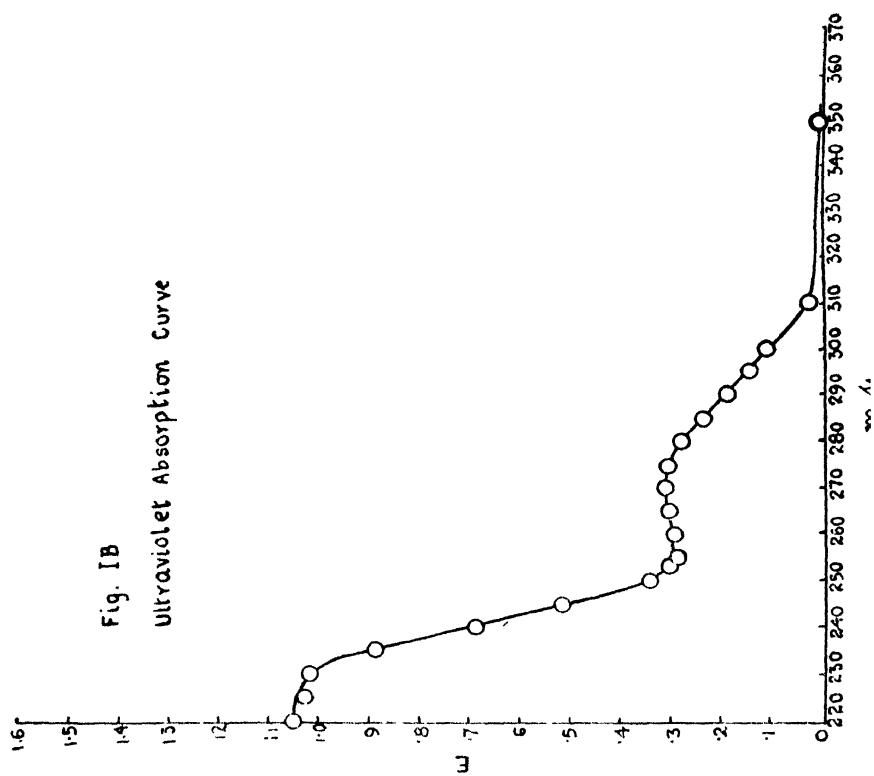
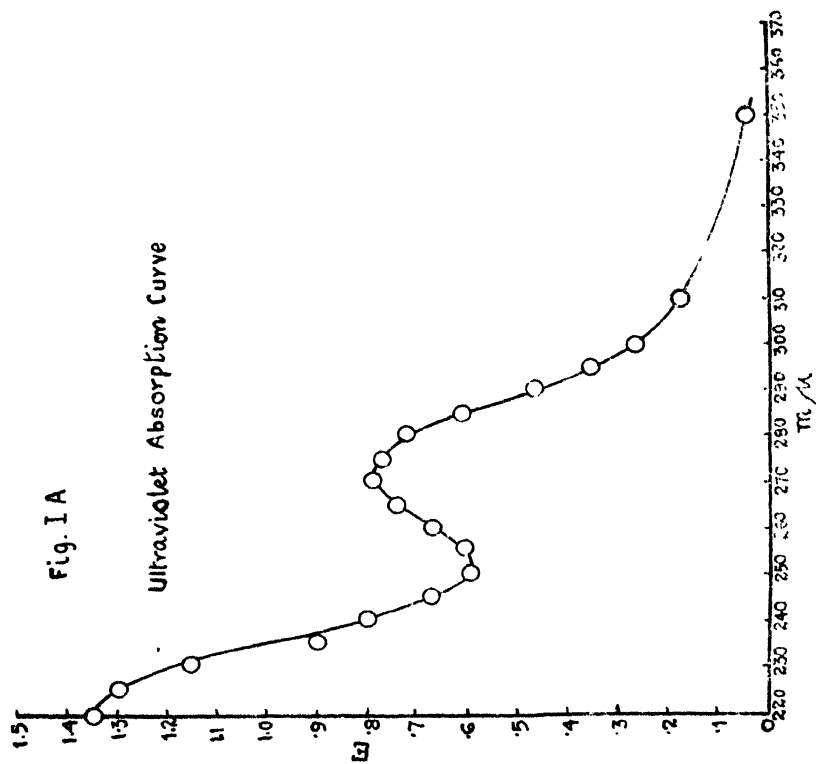


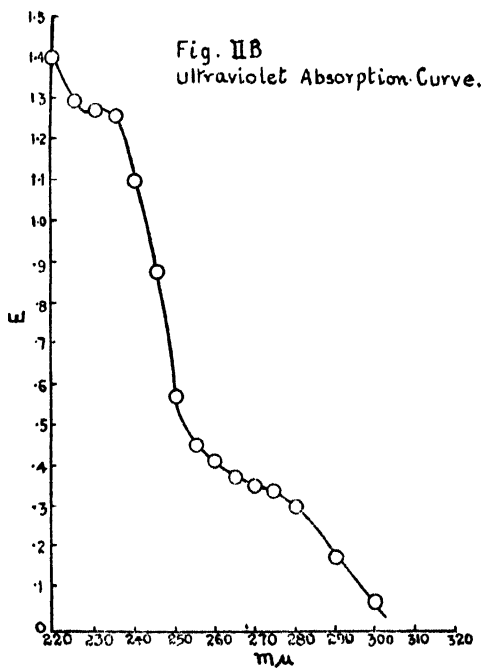
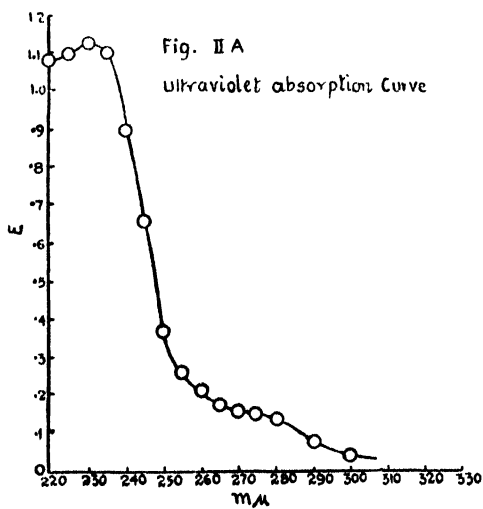
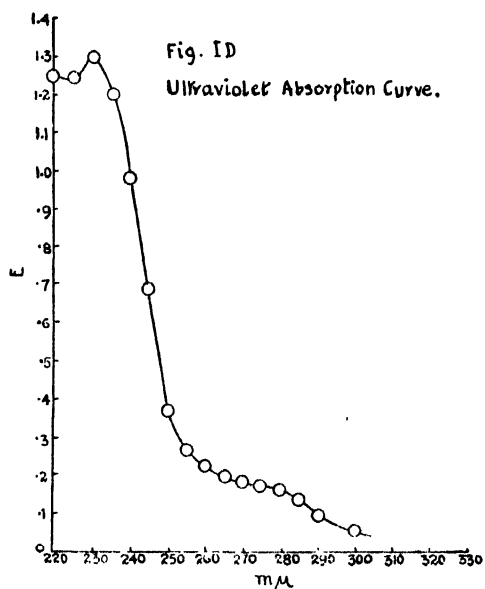
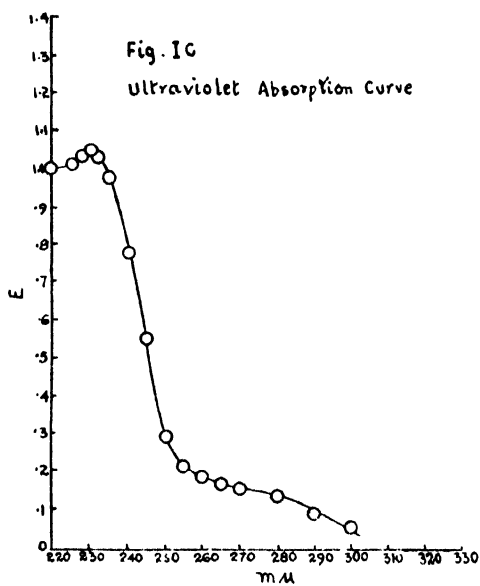
which had been prepared by Zetzsche, Meyer and Overback (1938). Zetzsche's method of preparing the compound referred to Dr. Brausch appeared to be peculiar in some respects. Bis- (*p*-dimethylamino phenyl) thiourea in benzene suspension was treated with litharge. In reactions of this type, the replacement of sulphur by oxygen might be expected and the production ought to have been bis- (*p*-dimethylamino phenyl) urea.

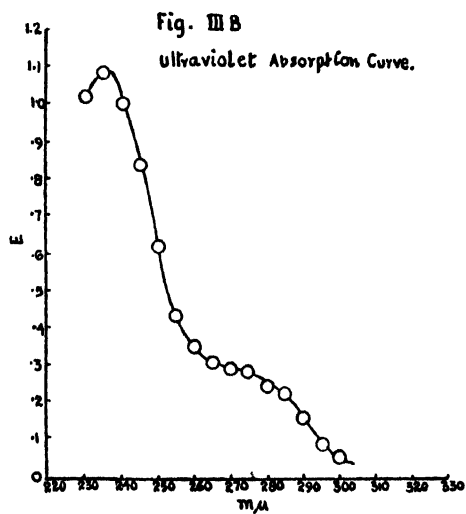
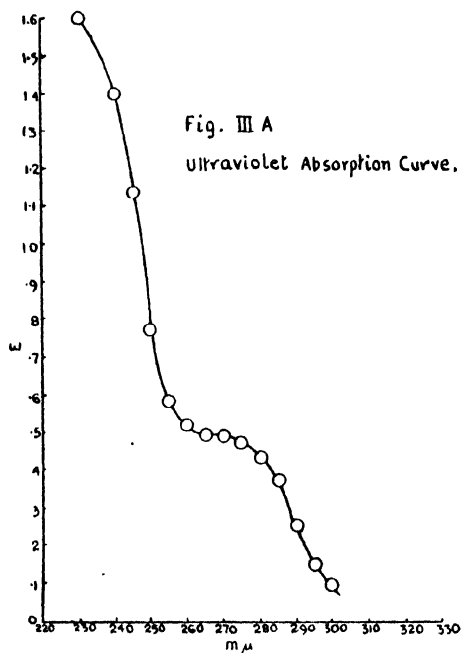
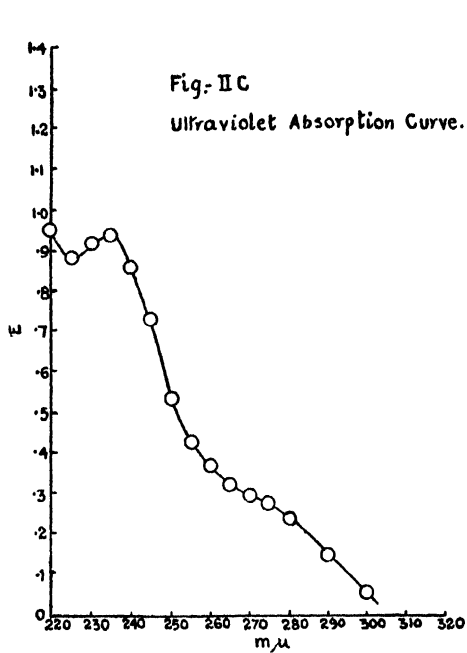


But the product isolated was a compound of m.p. 90-91°, which was stated to be the di-imid referred to before. In support of this di-imid structure, Zetzsche had referred to an earlier publication by Weith (1874). It appeared to us to be strange that a molecule of water was eliminated from the urea compound, in the absence of a dehydrating agent, as neither litharge nor lead sulphide can be considered to be a dehydrating agent in reactions of this type. Moreover, a di-imid compound of this type would bear a close resemblance in structure to isocyanates and would therefore condense with alcohol. But Zetzsche had stated that the substance could be crystallised from alcohol. Again, a compound of this type would react with water and hydrogen sulphide, in a suitable solvent, to give the corresponding urea and thiourea derivatives. Unfortunately, we were not successful in bringing about a reaction of this type. In the absence of any reply from Dr. Zetzsche, we cannot offer any explanation of these failures.

The only satisfactory method for determining the constitution of Zetzsche's di-imid was to determine the Raman spectra of the substance. Prof. Sircar, one of the associates of Prof. Raman in his work, was kind enough to undertake this for us, for which we express our sincere gratitude to him. The investigation on Raman spectra was carried out in benzene solution. Pure benzene shows a strong line at 1585 Å and a feeble one at 1686 Å. Using a benzene solution of the di-imid, the order was reversed. No characteristic line due to $-\text{N}=\text{C}=\text{N}-$ could be detected. According to Prof. Sircar, the reversal in the intensity of the line could not be regarded as due to the presence of the system $-\text{N}=\text{C}=\text{N}-$. The question of the constitution of Zetzsche's compound must therefore be left open for the present.







For determining the constitution of the fatty acids, *p*-phenyl phenacyl esters were hydrolysed by agitation with alcoholic caustic potash at ordinary temperature for a long period. This was considered necessary to avoid any shifting in the position of the double bonds. The acids were then separated by the usual method and the analytical data of the acids were determined immediately after the removal of the solvent. In the absence of a suitable ozoniser, the oxidative degradation was carried out in acetone solution (Armstrong and Hilditch, 1925).^{*} In the case of Fraction III_B, the oxidation was conducted in acetic acid solution (Armstrong and Hilditch, 1925).

It has been stated before that the most active portion of the ester was obtained in the distillate between 162° and 170°/0.3 mm. (III_B), while the fraction between 130° and 136°/0.06 mm. (I_B) was less active. The mode of action of these fractions, containing a C₂₄ diethenoid and a C₁₆ monoethenoid acid, is not clear. It may be that the unsaturated acids by themselves are responsible for the hypotensive action or they may be transformed in the body to effective agents. The evidence available at present indicates that the kidney is concerned with the pathogenesis of hypertension as it is observed in human as well as in experimental animals (Grollman, 1942). The rôle of kidney is not due to the production of a pressor agent as was formerly assumed but is best explained by assuming that the kidney normally supplies some agent essential for maintenance of the normal state and in the absence of which, hypertension ensues (Grollman, 1947). It might be assumed that the fortuitous presence of this substance, its precursor or a related compound in liver oils, accounts for this action.

EXPERIMENTAL.

Liver Oil of Galeocedro Tigrinus.— n_D^{30} , 1.4683; saponification value, 167.4; iodine value, 83.8.

Hydrolysis and separation of fatty acids.—The liver oil (2 kilo) was saponified with caustic potash (450 g.) in alcohol (95%, 10 litres) by heating under reflux for 4 hours. The solvent was then distilled off, the later stages being conducted under vacuo to get rid of the major part of alcohol. The dark brown soap was then dissolved in water (about 10 litres) with heating. The solution was cooled and continuously extracted with petroleum ether (b.p. 40–60°) for 48 hours to remove the unsaponifiable matters. The petroleum ether extract was evaporated and the residue was found to be inactive by the usual bio-assay method. To separate the unsaturated hydrocarbons, the residue was again taken up in dry petroleum ether and treated with bromine in slight excess. Excess of bromine was removed by a current of dry air and the solution concentrated to about half its volume and cooled overnight in a refrigerator. A solid separated which was probably the bromine addition product of the unsaturated hydrocarbons. This was filtered off and the filtrate evaporated to dryness. The residue containing sterols and vitamins was examined biologically and found to be inactive. These observations were sufficient to indicate that the active component was not present in the unsaponifiable fraction of the oil.

After the separation of the unsaponifiables, the soap solution cooled in ice and salt. For the extraction of the fatty acids, the soap solution, in portions of 2 litres, was transferred to a separating funnel, acidified with cold 4*N* sulphuric acid and the fatty acids extracted with ether (about 2 litres). The separated ethereal layer was washed free from mineral acid with ice-cold brine and dried over sodium sulphate. Removal of the solvent and drying the mixture fatty acids in vacuo over a steam bath gave a mixture of saturated and unsaturated acids (1700 g.).

Separation of saturated from the unsaturated fatty acids.—The fatty acids (1700 g.) were dissolved in 95% alcohol (8.5 litres) containing acetic acid (1.5 g./100 c.c. or 127.5 g.) and heated to boiling. Lead acetate (1190 g.) was dissolved in 95%

alcohol (11.9 litres) containing acetic acid (1.5 g./100 c.c. or 178.5 g.) and heated to boiling on a hot plate. The alcoholic solution of the fatty acids was rapidly added to the hot solution of lead acetate with vigorous stirring and the stirring continued for about 30 minutes after the addition was finished. The liquid was then allowed to stand overnight, the yellowish white crystalline precipitate of the lead salts of the saturated fatty acid was filtered off, the mass thoroughly pressed and washed with 95% alcohol containing 1.5 g. acetic acid per 100 c.c. A portion of the separated lead salt was decomposed with concentrated hydrochloric acid and the aqueous layer separated from the fatty acids. Traces of lead chloride were removed by thorough agitation with hot water and the fatty acids taken up in ether, washed with water and dried over sodium sulphate. Removal of the solvent and drying of the residual acids in *vacuo* on a steam bath gave a mixture of saturated fatty acids which solidified on cooling. These were tested by the biological method and found to be active and hence were discarded. (Iodine value, 4.72.)

The filtrate from the lead salts was distilled to remove the major portion of alcohol, the residual liquid cooled and taken up in ether (3 litres). The etherical solution was decomposed by thorough agitation with cold distilled water (twice) and the aqueous extract containing lead acetate was discarded. To decompose any remaining lead salt, the etherical layer was agitated with ice-cold dilute hydrochloric acid (10%, 1 litre), followed by two washings with ice-cold distilled water to remove lead chloride and traces of mineral acid and finally dried over sodium sulphate. Removal of the solvent and thorough drying in *vacuo* on an oil bath at 180°C. gave a residue consisting mainly of unsaturated acids (iodine value, 116.3). This was submitted to a second lead salt separation when the iodine value reached 123.1, a very small quantity of solid lead salt separating during this operation. Yield 900 g.

Esterification.—The unsaturated fatty acids (900 g.) were added to alcohol (5 litres) and sulphuric acid (*d* 1.84, 4.5 c.c.) and heated under reflux for 4 hours. About 2 litres of alcohol were distilled off and the residual liquid rapidly cooled in ice. The cooled liquid was then added to ice-cold brine (6 litres) in a separating funnel and the whole vigorously agitated and allowed to stand overnight. The aqueous portion was decanted, further diluted with cold brine (4 litres). Attempts were made to extract the esters present in this portion, in batches of 2 litres with ether (about 2 litres). Unfortunately, the separation of the organic solvent took a long time and the volume of the separated ether was very small (about 200 c.c.). In subsequent work, the extraction of this aqueous portion was dispensed with and the ester that might have been present in this portion was not recovered. The ester that had been obtained after the first dilution of the esterification mixture was taken up in ether (4 litres), washed with ice-cold brine (1,000 c.c.), then with a solution of sodium bicarbonate and finally with distilled water and dried over sodium sulphate. Removal of the solvent left a dark brown oil which was dried by heating on an oil bath to a temperature of about 180° (bath temperature) under 20 mm. The dried ester was employed for subsequent work.

The ethyl esters, in batches of 250 c.c., were distilled from a 500 c.c. Willstätter flask and the following fractions were collected:—

Fraction No.	Bath temp.	Head temp.	Pressure.	Vol. of distillate.
I ..	-203°	-140°	0.05 mm.	43 c.c.
II ..	203-220°	140-60°	0.06 mm.	130 c.c.
III ..	220-235°	160-70°	0.06 mm.	75 c.c.

When submitted to bio-assay, only Fraction III was found to be active while Fraction I showed moderate activity. But for the identification of the fatty acids, all the three fractions were redistilled. The data of the fractions are given below:—

Fraction No.	Bath temp.	Head temp.	Pressure.	Yield.	Sap. eq.	I.V.	Refractive index _D	<i>p</i> -phenyl phenacyl ester m.p.
<i>I—up to 140°</i>								
I _A ..	185°	120°	0.05 mm.	25 c.c.	196.3	50.63	1.4392	
I _B ..	185–90°	120–24°	0.06 mm.	40 c.c.	234.0	40.32	1.4410	
I _C ..	190–210°	124–30°	0.06 mm.	30 c.c.	200.6	77.25	1.4450	
I _D ..	210–15°	130–35°	0.06 mm.	15 c.c.	178.4	93.58	1.4470	89.90°
<i>II—140–60°</i>								
II _A ..	210–14°	140–44°	0.05 mm.	45 c.c.	231.2	79.0	1.4485	59.60°
II _B ..	214–24°	144–48°	0.05 mm.	45 c.c.	215.0	122	1.4550	90.91° + 65.66°
II _C ..	224–40°	148–56°	0.05 mm.	10 c.c.	186	116.4	1.4662	60.61°
<i>III—160–70°</i>								
III _A ..	210–14°	158–62°	0.05 mm.	45 c.c.	235.2	159	1.4683	64.65°
III _B ..	214–38°	162–68°	0.30 mm.	25 c.c.	183.2	235.1	1.4712	56.57°

Of these redistilled fractions, only III_B+I_D were found to be active by biological assay.

The low range of iodine values of I_A–I_C indicated that these were mixtures of the ethyl esters of saturated and unsaturated acids. In fact, the separation by this distillation procedure was not very efficient. The ultraviolet absorption spectra of these fractions were also examined and the data included later on.

p-Phenyl phenacyl ester of Fraction I_D.—The ethyl ester (10 g.) was saponified by heating with caustic potash (2 g.) in 95% alcohol (100 c.c.) for 3 hours. The alkaline solution was then neutralised with alcoholic hydrochloric acid and the solvent distilled off. The residual soap was dissolved in water (100 c.c.) and extracted with petroleum ether to remove any unsaponified ester. After the separation of the organic solvent, the aqueous solution was heated under reflux with *p*-phenyl phenacyl bromide (5 g.) for about 3 hours. To prevent excessive frothing, 95% alcohol (5 c.c.) was added from time to time. (Total 20 c.c.) The vessel was then allowed to stand overnight and the brownish residue filtered and washed to remove inorganic salts. Several crystallisations for 95% alcohol (with charcoal) gave colourless shining plates, m.p. 89.90° (compare Broughton, Bowman and Ames, 1952). (Found: C, 80.09; H, 9.37%; C₃₀H₄₀O₃ requires C, 80.00; H, 8.57%.) The combined filtrate was evaporated and a yellowish oil was left which could not be crystallised.

Hydrolysis.—The *p*-phenyl phenacyl ester (3 g.) was dissolved with heating in 95% alcohol (about 120 c.c.) and cooled. To this solution, solid caustic potash (2 g.) was added and the mixture was continuously agitated for 36 hours. The solid by-products of the reaction were filtered off and the dark brown alcoholic solution deprived of the solvent. The residue was taken up in water, extracted successively with ether and petroleum ether (40°–60°), and the aqueous solution acidified with dilute sulphuric acid and the separated fatty acid taken up in ether and dried over sodium sulphate (equivalent weight, 221.1; I.V., 99.83).

Oxidation.—The regenerated acid (5 g.) in acetone (100 c.c.) was treated with finely powdered potassium permanganate (20 g.) in small portions, and the mixture

carefully heated under reflux, after each addition during 1 hour. After this, the heating was continued for 10 hours. Solvent was distilled off and the residue treated with water (200 c.c.). The oxides of manganese were brought into solution by the addition of sodium bisulphite and dilute sulphuric acid. The acid solution was then cooled and extracted with ether. The ethereal extract was washed with cold brine and repeatedly extracted with 20% sodium carbonate, the continued alkaline extract being finally washed with ether. The alkali washed ethereal extract was evaporated, the residue being very small.

The alkaline extract was then cooled and carefully acidified with dilute sulphuric acid and extracted repeatedly with ether to take up the fatty acids. After removal of the solvent, the residue was boiled (thrice) under reflux, with petroleum ether (40–60°) for 1 hour and filtered from the insoluble portion. After removal of the solvent (petroleum ether), the residual monobasic acid was found to have the following constants: b.p. 220–22°, eq. weight, 129.3; *p*-phenyl phenacyl ester, m.p. 60–61°. These figures indicated that the monobasic acid was *n*-heptanoic acid.

The petroleum ether-insoluble material was crystallised for acetone, m.p. 103.4°, eq. weight, 93.2; *p*-phenyl phenacyl ester, m.p. 140–41°. These data indicate that the dibasic acid was azeleic acid.

Based on these observations, the acid which formed the starting material for these oxidative reactions must be Palmitoleic acid— $\text{CH}_3(\text{CH}_2)_5\text{CH} = (\text{CH}_2)_7\text{COOH}$ and the major portion of fraction I_D must be *ethyl palmitoleate*.

p-Phenyl phenacyl ester of Fraction II_A .—This derivative was prepared in a similar manner as in the case of Fraction I_D and after several crystallisations from 95% alcohol was obtained as shining leaflets, m.p. 60–61°. (Found: C, 80.64; H, 9.31, $\text{C}_{32}\text{H}_{44}\text{O}_3$ requires C, 80.67; H, 9.24%.) The m.p. and the analytical data agree with the ester of oleic acid.

Hydrolysis and oxidation.—The ester (30 g.) was hydrolysed as described before by dissolving in 95% alcohol (100 c.c.) and caustic potash (20 g.). After the usual operations, the acid (15 g.) was obtained by evaporation of the dried ethereal extract. (Eq. wt. 281.0, I.V. 81.29, *p*-phenyl phenacyl ester m.p. 61–62°.) The acid (15 g.) was oxidised in acetone solution with powdered potassium permanganate (60 g.) in the usual manner. The mixture of fatty acids thus obtained were separated into mono and dibasic acids by usual petroleum ether extraction. The petroleum ether soluble acids (about 6 g.) were distilled and the main fraction (3.5 g.) was collected between 250° and 255° (eq. wt. 146.1, *p*-phenyl phenacyl ester m.p. 71–72°). The acid was thus identified as Pelargonic acid or Nonanoic acid, $\text{CH}_3(\text{CH}_2)_7\text{COOH}$. The petroleum ether-insoluble dibasic acids were crystallised (thrice) for water when a fine crystalline product was obtained, m.p. 104.5°; eq. wt. 94.0; *p*-phenyl phenacyl ester m.p. 139–40°. This acid was therefore identical with azeleic acid, $\text{COOH} \cdot (\text{CH}_2)_7 \cdot \text{COOH}$. The original acid was therefore oleic acid, $\text{CH}_3(\text{CH}_2)_7\text{CH} = \text{CH} \cdot (\text{CH}_2)_7\text{COOH}$.

p-Phenyl phenacyl ester of Fraction II_B .—The crude ester prepared by the usual manner, was crystallised from 95% alcohol in shining plates, m.p. 90–91°. The filtrate was diluted with water till it was cloudy and the solution heated to give a clear solution. On standing overnight, another crop of crystals was obtained which melted at 63–65°. Recrystallised from dilute alcohol (twice) m.p. 65–66°. (Found (Product m.p. 90–91°): C, 80.51; H, 9.34%. (Product m.p. 65–66°): C, 80.47; H, 9.39%; $\text{C}_{32}\text{H}_{42}\text{O}_3$ requires C, 80.68; H, 9.21%.)

Hydrolysis.—After saponification by the method described before, the acid that was obtained had an equivalent weight 279.1, I.V. 179.4, D, 1.4677, *p*-phenyl phenacyl ester m.p. 90–91°. It was considered that the acid in question was linoleic acid and this was confirmed by the preparation of tetra bromide, m.p. 112–13°, which was not depressed when mixed with an authentic specimen of tetra-

bromo stearic acid (compare Ralph and Sondheimer, 1950). The two *p*-phenyl phenacyl esters—m.p. 90-91° and m.p. 65-66°—appear to be isomers.

p-Phenyl phenacyl ester of Fraction II_C.—The ester obtained from this fraction was a pasty mass which was dried on a porous plate. The yellowish white solid was crystallised from 95% alcohol (with charcoal) and methanol. In each case, a crystalline material of m.p. 60-61° was obtained. (Found: C, 81.27; H, 8.59; C₃₂H₄₀O₃ requires C, 81.35; H, 8.48%.) This ester was hydrolysed back into the acid. Eq. wt. 277.3, I.V. 259.2, *p*-phenyl phenacyl ester m.p. 61-62°. From these data it appeared that the product was a triethenoid acid. The mixed m.p. of *p*-phenyl phenacyl ester of oleic acid and of this product was found to be 45-50°. The sample was therefore not derived from oleic acid. The high iodine value indicated that it was linolenic acid but the quantity was too small for the usual oxidative degradation studies.

p-Phenyl phenacyl ester of Fraction III_A.—The ester was prepared by the usual method and recrystallised for 95% alcohol (with charcoal). M.P. 64-65° (found: C, 80.57; H, 9.49%; C₃₄H₄₈O₃ requires C, 80.63; H, 9.83%). The regenerated acid from the phenacyl ester was found to have an eq. wt. 309.2, I.V. 80.60, *p*-phenyl phenacyl ester m.p. 64-65° (compare Broughton, Bowman and Ames, 1952).

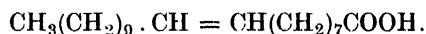
The acid (10 g.) was oxidised in acetone solution with powdered potassium permanganate (40 g.). The monobasic acid fraction was distilled under vacuo—b.p. 120-22/0.1 mm., eq. wt. 185.3, *p*-phenyl phenacyl ester m.p. 78-79°. Mixed m.p. with *p*-phenyl phenacyl ester undecanoic acid was not depressed.

The monobasic acid was thus found to be undecanoic acid CH₃.(CH₂)₉.COOH.

The dibasic acid portion was identified as azeleic acid from the data given below:—

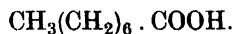
M.P. 104.5°, eq. wt. 94.1, *p*-phenyl phenacyl ester m.p. 140-41°.

The original acid is therefore Eicos 9-enolic acid or Gadoleic acid.



p-Phenyl phenacyl ester of fraction III_B.—The ester was prepared in the usual manner and the pasty mass, after being dried on a porous plate, was crystallised from methanol in white glistening plates. M.P. 56-57° (found: C, 81.66; H, 9.88%; C₃₈H₅₄O₃ requires C, 81.77; H, 9.70%).

Hydrolysis and oxidation.—The ester was hydrolysed as usual and the acid had the following characteristics: Eq. wt. 361.3, I.V. 138.8, *p*-phenyl phenacyl ester m.p. 56-57°. The acid (10 g.) was oxidised in acetic acid (60 c.c.) and potassium permanganate (20 g.) at 100° for 4 hours. Acetic acid was distilled off under vacuo from a water bath and the residue treated with water (250 c.c.). The oxides of manganese were brought into solution by the addition of sodium bisulphite and dilute sulphuric acid. The extraction of the organic acids followed the usual course and the mixture of acids were separated into mono and dibasic acids by repeated extraction with petroleum ether. The petroleum ether extract, after removal of the solvent, gave on distillation a fraction b.p. 235-37°, eq. wt. 142.3, *p*-phenyl phenacyl ester m.p. 65-66°. The acid under investigation was therefore caprylic acid

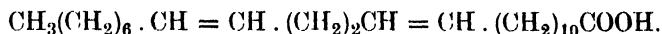


The petroleum ether-insoluble portion was found to be a mixture. The separation of the acids was effected by triturating the mass with cold water and filtering off the less insoluble portion. The filtered solution was concentrated to about half its volume on a water bath and cooled in ice. The solid that separated was subjected to the same operation again and a fine crystalline material was finally obtained. M.P. 187-88°, eq. wt. 58.0, *p*-phenyl phenacyl ester m.p. 218-19°. These figures were identical with the constants of succinic acid which were confirmed

by mixed m.p., determination of the free acid and also of the *p*-phenyl phenacyl ester with authentic succinic acid and its *p*-phenyl phenacyl ester. Cold water extraction of the crude dibasic acids gave succinic acid— $\text{HOOC} \cdot (\text{CH}_2)_2 \cdot \text{COOH}$.

The residue left after trituration with cold water was crystallised (thrice) from acetone and was finally obtained in long needle shaped crystals, m.p. 122-23°, eq. wt. 114.2, anilide m.p. 191°, *p*-bromo anilide m.p. 213°. From these data, the dibasic acid was identified as *n*-decane dicarboxylic acid (Bannierat, 1927).

The oxidative degradation gave three acids: (1) *n*-caprylic acid, (2) succinic acid, (3) *n*-decane dicarboxylic acid. On these observations, the original acid might be considered to be a C_{24} diethenoid acid of the following structure:—



ABSTRACT.

Some of the constituent unsaturated acids of the liver oil of *Galeocedro tigrinus* have been identified by the formation of *p*-phenyl phenacyl ester. The constitution of these acids has been determined by oxidation with potassium permanganate. The acids isolated and identified in this paper are the following: Palmitoleic, Oleic, Linoleic, Linolenic, Gadoleic and Tetracos 12 : 16 *di*-conic acid.

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ON THE EXPLOSION OF O₂ NEGATIVE EXPLOSIVES

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1. INTRODUCTION.

In a recent publication Cottrell and Paterson (1952) have made use of the cell model for a compressed gas to write down an equation of state for gases at densities approaching that of solids, and have applied it to explore the detonation properties of O₂ balanced explosive PETN. In this case because the products of explosion are mainly determined by the water gas equilibrium, only the internal energy of the products has to be corrected. On the other hand, the products of O₂ negative explosives do not get determined unless some equilibria in addition to the water gas are considered. In that case the equilibrium constants of the reaction concerned have also to be modified. The presence of the condensed phase among the products introduces another unknown parameter. The present is an attempt to extend the application of the above-mentioned cell model to the investigation of the properties of explosion—deflagration and detonation of O₂ negative explosives and to work out the solutions for TNT for various loading densities.

The behaviour of any explosive in exhibiting deflagration or detonation depends on the physical and chemical properties of the explosive, and on the method of initiation. A mass of the high explosive may be completely detonated if a powerful shock wave is sent through it. Experimental evidence also exists (*Science in World War II*, 1948) to support that the same may be deflagrated in full in a closed vessel if conditions are controlled, e.g. it is initiated simultaneously at a number of places, and no pressure surges are allowed to develop. On the other hand, depending on the environment the simple burning of the explosive may change into detonation, after a certain critical mass, determined by its chemical constitution, has been burnt away. This sort of transformation into detonation is associated with the formation of shocks due to resistance to flow products, and the rapid rise of the reaction rate with pressure. As mentioned above, however, a certain specified state of the products can be reached either through complete deflagration or complete detonation. In the latter case each element of the explosive has to pass through the detonation wave, get initiated and the products irreversibly compressed to a volume much less than the original volume of the explosive. During the latter operation the entropy of the products increases. Later when the products reach the original volume again after adiabatic expansion they will have the entropy corresponding to the composition in the wave front. Comparing the entropies of the products in the detonation wave front with those obtained by burning in constant volume explosion, the amount of entropy created during the irreversible compression can be evaluated. In the present work such calculations have been made for TNT for a loading density of 1.0 gm./c.c.

2. THEORY OF CHEMICAL EQUILIBRIUM.

The basic equation of state used is the same as used by Cottrell and Paterson (1952), namely

$$\left. \begin{aligned} p &= nRT g_v \\ g &= \log \int_0^v e^{-W/nRT} dv \end{aligned} \right\} \cdots \cdots \cdots (1)$$

symbols having their usual significance, and the suffix denoting partial differentiation. W is the interaction energy due to repulsion per mole of the gaseous products and is taken to be $X v^{-2}$; v being the volume available per mole of the gas. The value of X per mole of the gaseous products is chosen to be that suggested by the calculations on H_2 molecule ion and adjusted so that the experimental data on detonation velocity for PETN agree with the calculations. For O₂ negative explosives the number of gm. moles of the products is not independent of temperature and pressure corrections (as for a water gas reaction used for determining the products of PETN) and therefore it is convenient to put $X = \xi n^3$, n being the number of moles of the products for one gm. mole of the explosive. The value of ξ is taken to be as suggested above. With any value of n assumed a new value of X enters the equations.

The equation (1) above essentially embodies the assumption that the equation of state is independent of the composition of the gases and the absolute activity p_i^* of the constituent is the same as that for the mixture.

p_i^* is given by

$$\ln p_i^* = \frac{1}{RT} \int_v^\infty \left[\left(\frac{\partial p}{\partial n_i} \right)_{vTn} - \frac{RT}{v} \right] dv - \ln \frac{v}{n_i RT} \quad \dots \quad (2)$$

$$\begin{aligned} &= \int_v^\infty \left[ng_{vi} + g_v - \frac{1}{v} \right] dv - \ln \frac{v}{n_i RT} \\ &= \left[ng_{ni} \right]_v^\infty + \int_v^\infty \left(g_v - \frac{1}{v} \right) dv - \ln \frac{v}{n_i RT} \quad \dots \quad (3) \end{aligned}$$

$$g_{ni} = \frac{xe^{x^2} \cdot \sqrt{\pi} \operatorname{erf} c(x)}{n [\sqrt{\pi} \operatorname{erf} c(x) xe^{x^2} - 1]}$$

$$x^2 = \frac{X}{nRTv^2} = \frac{\xi n^2}{RTv^2}$$

$$\operatorname{erf} c(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-x^2} dx.$$

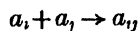
$$\begin{aligned} \int_v^\infty \left(g_v - \frac{1}{v} \right) dv &= \lim_{V \rightarrow \infty} \int_v^V \left(g_v - \frac{1}{v} \right) dv \\ &= \lim_{V \rightarrow \infty} [g(V) - \log V] + (\log v - g) \quad \dots \quad (4) \end{aligned}$$

$$\begin{aligned} &= \lim_{V \rightarrow \infty} [g(V) - \log V] = \lim_{V \rightarrow \infty} \left[\log \frac{\int_0^V e^{-\frac{X}{nRTv^2}} dv}{V} \right] \\ &= \lim_{V \rightarrow \infty} - \frac{X}{nRTV^2} = 0 \end{aligned}$$

\therefore Equation (3) gives

$$\begin{aligned} \ln p_i^* &= -(ng_{ni} + g) + \ln n_i RT \\ p_i^* &= n_i RT e^{-(ng_{ni} + g)} \quad \dots \quad (5) \end{aligned}$$

For a reaction like



$$\frac{p_{ij}^*}{p_i^* p_j^*} = K_0$$

$$\frac{n_{ij}}{n_i n_j} = \frac{e^{(n g_{n_i} + k)}}{RT} \cdot K_0 \quad \dots \quad \dots \quad \dots \quad (6)$$

K_0 being the equilibrium constant for perfect gas condition.

3. DEFLAGRATION AND DETONATION.

For the simple burning process the temperature of explosion is determined by the condition $(E - H) = 0$, where E is the internal energy of the products of explosion and H the heat of the reaction. On the other hand, if the explosive undergoes detonation, the application of the laws of conservation of mass, momentum and energy across the discontinuity leads to the well-known Huginiot equation

$$E - H = \frac{1}{2} p(v_0 - v) \quad \dots \quad \dots \quad \dots \quad (7)$$

p and v being the pressure and volume in the detonation wave front and v_0 being the specific volume. E is given by

$$E = \sum n_i \int_0^T C_{v_i}^* dT + n_i E_i + n RT^2 g_T \quad \dots \quad \dots \quad \dots \quad (8)$$

and H by

$$H = \sum n_i \epsilon_i - \epsilon_{\text{TNT}} \quad \dots \quad \dots \quad \dots \quad (9)$$

($C_{v_i}^*$ being the specific heat at constant volume at infinite dilution, ϵ_i the heat of formation of the constituent i and ϵ_{TNT} that of TNT. It can be shown that

$$n g_{n_i} + 2 T g_i = 0 \quad \dots \quad \dots \quad \dots \quad (10)$$

$$n g_{n_i} + v g_v - 1 = 0 \quad \dots \quad \dots \quad \dots \quad (11)$$

In the case of burning the final volume of the products is fixed by the loading density of the explosive, while for detonation it has to be determined from equation (7). For O₂ negative explosives the volume of the solid carbon present which becomes known from the composition introduces an unknown parameter.

At a certain temperature T , and volume v_g of the gaseous products having the total number of moles equal to n , the composition is worked out. At this T and v_g calculations are repeated till the value of n obtained agrees with that assumed for it. The final composition so determined gives the volume of the solid carbon v_c and hence the total volume v . This final volume should correspond to the initial specific volume for the burning process while for detonation it should lead to the right value of v_0 as found out from equation (7). Calculations are repeated at different temperatures. The temperature at which $E = H$ gives the explosion temperature. For finding out the conditions in the wave front the curve given by equation (7) has to be drawn. At each temperature the value of p and v satisfying Huginiot equation enables this to be accomplished. The value of p and v at the tangent point to this curve gives the conditions in the detonation wave front.

The entropy S is given by

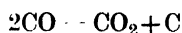
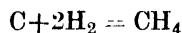
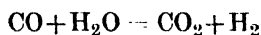
$$S = nRT g_T + nRg - nR \log v + \sum n_i R \ln \frac{v}{n_i RT} + \sum n_i S_i^0 + n_s S_c \quad \dots (12)$$

$$S_i^0 = S_{0i}^0 + \int_{T_0}^T \frac{C_{vi}^*}{T} dT + R \ln \frac{T}{T_0}$$

S_{0i}^0 is the entropy of the constituent i at the reference temperature T_0 ; C_{vi}^* the specific heat at infinite volume, S_c the entropy/gm. mole of carbon at one atmosphere. Effect of pressure on the entropy of the solid phase is neglected.

CALCULATIONS FOR TNT.

In order to determine the composition of the products the following equilibria may be considered:—



If K_1 , K_2 and K_3 are the equilibrium constants for these reactions in case the products form a perfect gas, and α , β , γ , δ , ϵ , η are the number of moles of CO_2 , CO , H_2O , H_2 , CH_4 and C , we have

$$\frac{\beta\gamma}{\alpha\delta} = K_1$$

$$\frac{\delta^2}{\epsilon} = K_2 \cdot \frac{e^{(\eta g_{n_i} + \epsilon)}}{RT}$$

$$\frac{\beta^2}{\alpha} = K_3 \cdot \frac{e^{(\eta g_{n_i} + \epsilon)}}{RT}$$

This of course involves the assumption that no nitrogen compounds are formed among the products. The above equations along with those given by the conservation of atomic types enable the relative amounts of different products to be assessed under any assumed conditions. Temperature of explosion is that which makes $E - H = 0$ while the tangent to the curve of equation (7) gives the conditions in the detonation wave front. The velocity of detonation D is given by

$$D^2 = \frac{p}{v_0 - v} v_0^2$$

in which p and v are the pressure and volume in the detonation wave front and v_0 the specific volume of the original explosive.

In the first instance the value of ξ used was the same as in (I) above, namely, 5.67 cal. cm.⁶/(mole)³. This value of ξ gave the value of D at density .74 gm./c.c. as 4,170 metres/sec. about 5% more than the value obtained experimentally. The value of ξ reduced to 4.4 cal. cm.⁶/(mole)³ gave a better agreement giving the calculated value of $D = 4,059$ metres/sec. It would appear that the value as used in (I) would have to be adjusted to get the right value of D in the case of TNT. The reason lies in the fact that as opposed to the case of an O_2 balanced explosive, in which case the number of moles of the gaseous products/gm. of the explosive is independent of the pressure and temperature and exclusively depends on the explosive composition, it depends on both in the case of TNT. For the same reason

no single value of ξ can give an exact agreement of detonation velocity over the entire range of loading densities, and a new value of ξ has to be found for each new value of ρ_0 . Table 1 gives the value of ξ for each loading density ρ_0 .

TABLE 1.

ρ_0 gm./c.c.	ξ cal. cm. ⁶ / (mole) ³	$p \times 10^{-10}$ dynes/cm. ²	v c.c.	$T^\circ\text{K}$	$D_{\text{cal.}}$	$D_{\text{obs.}}$
0.74	4.40	4.01	206.0	3240	4,059	3,970
1.00	6.20	5.98	170.7	3200	4,905	4,900

Table 2 gives the data for the entropy of products for constant volume explosion and detonation for $\rho_0 = 1.0$ gm./c.c.

TABLE 2.

Path.	Products in number of moles.								Gaseous volume $v_{\text{g.c.c.}}$	Temperature $T^\circ\text{K}$	Entropy S cal./deg./gm. mole TNT.
	CO ₂	CO	H ₂ O	H ₂	CH ₄	N ₂	C	n			
Burning ..	1.608	1.688	1.096	0.151	0.627	1.500	3.077	6.660	210.5	2880	150.55
Detonation	1.995	0.762	1.248	0.059	0.596	1.500	3.647	6.150	151.0	3200	141.67

Entropy created during irreversible compression is therefore the difference between the last two columns = 8.88 cal./degree/gm. mole TNT.

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ABSTRACT.

The application of the cell model for a compressed gas has been extended to the investigation of the properties of the explosion products of O₂ negative explosives. Numerical solution is provided for the detonation in TNT for various loading densities. The amount of entropy created during the irreversible process of detonation has been evaluated.

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THERMAL SCATTERING OF LIGHT IN BIREFRINGENT CRYSTALS.

INTENSITIES OF BRILLOUIN COMPONENTS

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1. INTRODUCTION.

In a previous communication on the thermal scattering of light in crystals, hereafter referred to as Part III, the author (Chandrasekharan, 1951) has shown for the first time that, in general, there must be twelve pairs of Doppler-shifted or Brillouin components in the light scattered by birefringent crystals. These arise because the Doppler shifts depend on the velocities of the incident and the scattered light waves inside the crystal and in each direction there are two possible velocities for the light waves. The expected frequency shifts and polarisation characteristics were also dealt with in that paper. Expressions for the intensities of the various Doppler components for arbitrary directions of incidence and of scattering have now been derived in terms of the elastic and photoelastic constants and the refractive indices of the crystal, and have been employed to evaluate the intensities of the Doppler components in calcite and quartz for specific crystal orientations. The results are presented in this paper.

2. GENERAL THEORY.

In order to derive expressions for the intensities of the Brillouin components of the light scattered by crystals, we can use a reasoning similar to that employed by Mueller (1938) for the scattering of light by amorphous substances. According to Mueller, the light scattered by a unit volume of the substance at unit distance is given by

$$I = \frac{\pi^2}{\lambda^4} \frac{U(K_B)}{c} D_n^2(K_B) \quad \dots \quad \dots \quad \dots \quad (1)$$

where $U(K_B)$ is the density of potential energy of the Bragg wave, c is the reciprocal of the adiabatic compressibility and $\vec{D}_n(K_B)$ is the component normal to the directions of observations of a vector $\vec{D}(= \epsilon \vec{E}_0)$. \vec{E}_0 is the amplitude of the incident light vector and ϵ is the amplitude of the variation of the optical dielectric constant produced by a Bragg wave of amplitude $A = 1/K_B$. In the case of isotropic solids c must be replaced by the elastic constants c_{11} for longitudinal and by c_{44} for transverse waves.

In the more general case to be considered here, the Bragg wave λ_B is replaced by the elastic wave λ_e . Also in the thermal scattering of light in crystals, λ_e is of the same order as λ and hence if $\lambda > 2000\text{\AA}$, equipartition of energy is valid and the energy of each mode is $U = kT/2$ as in isotropic solids (or liquids). We shall use the following notation. λ is the wavelength of the incident light, \vec{R}_e is the wave vector of the elastic wave having its direction parallel to the direction of propagation

of the wave and the magnitude $2\pi/\lambda_e$. Then the intensity of the light scattered per unit volume per unit solid angle is

$$I = (\pi^2/\lambda^4)kT/2c \cdot [D_I^S(R_e)]^2 \quad \dots \quad (2)$$

where $D_I^S(R_e)$ is the component of the elastic moment effective in scattering for the particular directions of incidence and of scattering. Consider for simplicity an optically inactive birefringent crystal. For given directions of the incident wave \vec{I} and of the scattered wave \vec{S} , the plane of scattering T is uniquely defined. Then, unlike in isotropic media, only two directions of vibrations are permissible for the incident wave. Let the unit vectors along these directions be designated by \vec{A} and \vec{B} . Similarly, let \vec{P} and \vec{Q} denote the two unit vectors parallel to the vibration directions of the scattered wave. Then according to the well-known laws of propagation of light

$$\vec{A} \times \vec{B} = \vec{I} \quad \dots \quad (3)$$

$$\vec{P} \times \vec{Q} = \vec{S} \quad \dots \quad (4)$$

and if θ is the angle of scattering,

$$\vec{I} \cdot \vec{S} = \cos \theta \quad \dots \quad (5)$$

In general, none of the vectors \vec{A} , \vec{B} , \vec{P} or \vec{Q} is parallel to the plane of scattering. Since either incident wave A or B can give rise to either of the scattered waves P or Q , there are, in general, the four possible species P_A , P_B , Q_A and Q_B mentioned in Part III. For each of these species the state of polarisation of both the incident wave and the scattered wave is uniquely defined. These determine the direction of propagation of the elastic wave responsible for the scattering of each one of these species, as given in section 7 of Part III. In general, these elastic wave vectors R_e will be different for the different species although they will be in the plane of scattering T ($EFGH$). In Fig. 1 are indicated the various vectors.

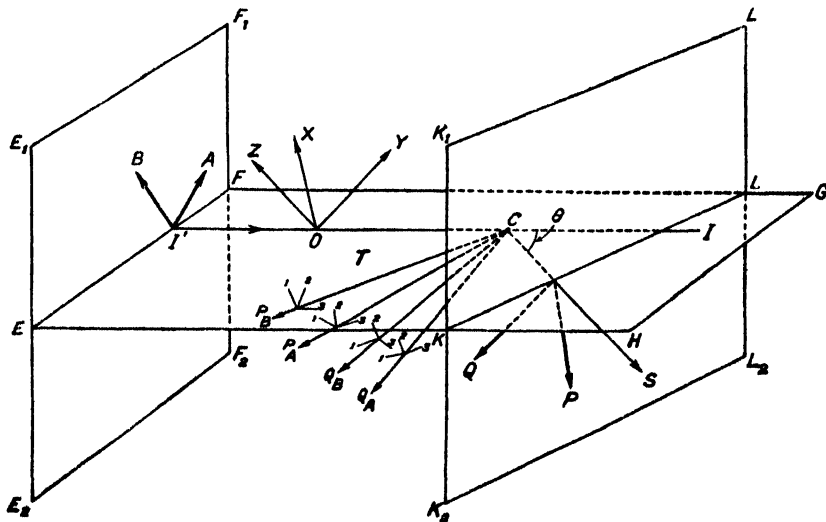


FIG. 1.

$E_1F_1F_2E_2$ is the incident wave front, the vectors \vec{A} and \vec{B} lying in it.

$K_1L_1L_2K_2$ is the scattered wave front, \vec{P} and \vec{Q} lying in it.

C is the scattering centre and OX , OY and OZ are parallel to the principal axes of the optical polarisability ellipsoid.

An elastic wave in a crystal creates photoelastic effects, i.e., it alters the components of the optical dielectric constant tensor. We may denote the change produced in the component ϵ_{ij} by $\Delta\epsilon_{ij}$ and symbolically represent the changes in the tensor by the tensor $[\Delta\epsilon]$ which should obviously be symmetric. For the different species P_A , P_B , Q_A and Q_B , the $[\Delta\epsilon]$'s are different and may be denoted respectively as $[\Delta\epsilon]_A^P$, etc. For any particular species, say P_A , the incident electric vector is parallel to \vec{A} and induces a moment

$$\vec{D} = [\Delta\epsilon]_A^P \vec{A} \quad \dots \quad \dots \quad \dots \quad \dots \quad (6)$$

Now the electric vector of the scattered wave is also defined for any species and in this case is along \vec{P} . Consequently, only the component of \vec{D} in equation (6) parallel to \vec{P} will be effective in scattering. This moment is given by

$$D_A^P = (\vec{P} \cdot [\Delta\epsilon]_A^P \cdot \vec{A}) \vec{P}$$

Similarly, for the other species

$$\left. \begin{aligned} D_A^Q &= (\vec{Q} \cdot [\Delta\epsilon]_A^Q \cdot \vec{A}) \vec{Q} \\ D_B^P &= (\vec{P} \cdot [\Delta\epsilon]_B^P \cdot \vec{B}) \vec{P} \\ D_B^Q &= (\vec{Q} \cdot [\Delta\epsilon]_B^Q \cdot \vec{B}) \vec{Q} \end{aligned} \right\} \quad \dots \quad \dots \quad \dots \quad (7)$$

If A_x , A_y , A_z are the components of the vector \vec{A} along the co-ordinate axes, we have firstly for the species P_A

$$\left. \begin{aligned} D_x &= \Delta\epsilon_{xx}A_x + \Delta\epsilon_{xy}A_y + \Delta\epsilon_{xz}A_z \\ D_y &= \Delta\epsilon_{xy}A_x + \Delta\epsilon_{yy}A_y + \Delta\epsilon_{yz}A_z \\ D_z &= \Delta\epsilon_{xz}A_x + \Delta\epsilon_{yz}A_y + \Delta\epsilon_{zz}A_z \end{aligned} \right\} \quad \dots \quad \dots \quad \dots \quad (8)$$

and if P_x , P_y , P_z are the components of \vec{P} along the co-ordinate axes

$$D_A^P = D_xP_x + D_yP_y + D_zP_z \quad \dots \quad \dots \quad \dots \quad (9)$$

Now along each of the four directions \vec{R}_s (marked in Fig. 1 as P_A , P_B , Q_A and Q_B) there are propagated three types of elastic waves travelling with different velocities $v_s = \sqrt{q_s/\rho}$, where ρ is the density of the crystal and q_s the stiffness coefficient for the particular wave. In an elastically isotropic solid q_s takes the value c_{11} for longitudinal and c_{44} for the two transverse waves for all directions of propagation. Mueller has shown that these replace c in equation (1). Similarly, for an anisotropic solid the appropriate values of the q_s 's must replace c in Eq. (2). These can be calculated from the Christoffel equations, as shown a little later. Let q_1, q_2, \dots, q_{12} be the values of q_s for the twelve elastic waves responsible for the scattering of the 12 pairs of Doppler components. Thus leaving out the constant factor

$\pi^2 kT/2\lambda^4$, we have from (2) and (7) the following equations for the intensities of each of the 12 pairs of Doppler components:—

$$\left. \begin{aligned} {}_1I_A^P &= ({}_1D_A^P)^2/q_1 = (\vec{P} \cdot {}_1[\Delta\epsilon]_A^P \vec{A})^2/q_1 \\ {}_2I_A^P &= ({}_2D_A^P)^2/q_2 = (\vec{P} \cdot {}_2[\Delta\epsilon]_A^P \vec{A})^2/q_2 \\ {}_3I_A^P &= ({}_3D_A^P)^2/q_3 = (\vec{P} \cdot {}_3[\Delta\epsilon]_A^P \vec{A})^2/q_3 \\ {}_1I_A^Q &= ({}_1D_A^Q)^2/q_4 = (\vec{Q} \cdot {}_1[\Delta\epsilon]_A^Q \vec{A})^2/q_4 \\ {}_2I_A^Q &= ({}_2D_A^Q)^2/q_5 = (\vec{Q} \cdot {}_2[\Delta\epsilon]_A^Q \vec{A})^2/q_5 \\ {}_3I_A^Q &= ({}_3D_A^Q)^2/q_6 = (\vec{Q} \cdot {}_3[\Delta\epsilon]_A^Q \vec{A})^2/q_6 \\ {}_1I_B^P &= ({}_1D_B^P)^2/q_7 = (\vec{P} \cdot {}_1[\Delta\epsilon]_B^P \vec{B})^2/q_7 \\ {}_2I_B^P &= ({}_2D_B^P)^2/q_8 = (\vec{P} \cdot {}_2[\Delta\epsilon]_B^P \vec{B})^2/q_8 \\ {}_3I_B^P &= ({}_3D_B^P)^2/q_9 = (\vec{P} \cdot {}_3[\Delta\epsilon]_B^P \vec{B})^2/q_9 \\ {}_1I_B^Q &= ({}_1D_B^Q)^2/q_{10} = (\vec{Q} \cdot {}_1[\Delta\epsilon]_B^Q \vec{B})^2/q_{10} \\ {}_2I_B^Q &= ({}_2D_B^Q)^2/q_{11} = (\vec{Q} \cdot {}_2[\Delta\epsilon]_B^Q \vec{B})^2/q_{11} \\ {}_3I_B^Q &= ({}_3D_B^Q)^2/q_{12} = (\vec{Q} \cdot {}_3[\Delta\epsilon]_B^Q \vec{B})^2/q_{12} \end{aligned} \right\} \dots \dots (10)$$

Equations (10) are the fundamental equations for obtaining the intensities of the various components for any specific crystal orientation. The sum of the intensities of a pair of components on either side of the original spectral line, having the same shift, is double this value since both components should be sensibly equal in intensity at room temperatures. But if natural unpolarised light of unit intensity is incident then $E_A = E_B = 1/\sqrt{2}$ and consequently, equations (10) would give directly the sum of the intensities of the two components in each pair.

3. RECIPROCAL RELATIONS.

The twelve equations (10) are symmetrical with respect to vibration directions \vec{A} , \vec{B} of the incident light wave and \vec{P} , \vec{Q} of the scattered light wave. Also $[\Delta\epsilon]$'s of these equations are symmetrical. Consequently, if for example the incident wave along \vec{I} with the vibration direction \vec{A} gives rise to a scattered wave \vec{S} with vibration direction \vec{P} and we consider the inverse set-up, viz., the incident wave \vec{P} along \vec{S} and a scattered wave \vec{A} along \vec{I} , both being scattered from the same centre C , then the intensity of scattering in the two cases should be same (cf. Perrin, 1942). Thus we have an example of a reciprocal experiment in which the states of polarisation of the light waves are clearly defined. Again, if the incident light in unpolarised and of unit intensity and the directions of incidence and of observation interchanged as defined in Part III, not only the shifts but also the intensities of the various components remain unaltered.

4. EVALUATION OF THE VELOCITIES AND DIRECTIONS OF VIBRATION OF ELASTIC WAVES.

In order to calculate the stiffness coefficients q , in equations (10) we make use of the well-known Christoffel's theory of propagation of plane elastic waves in an elastically anisotropic medium. It is given in many text-books (e.g. Cady, 1946). According to this theory, q is one of the three roots q_1 , q_2 and q_3 of the cubic equation.

$$\begin{vmatrix} A_{11}-q & A_{12} & A_{13} \\ A_{12} & A_{22}-q & A_{23} \\ A_{13} & A_{23} & A_{33}-q \end{vmatrix} = 0 \quad \dots \quad (11)$$

where

$$\left. \begin{aligned} A_{11} &= l^2 c_{11} + m^2 c_{66} + n^2 c_{55} + 2mnc_{56} + 2nlc_{51} + 2lmc_{16} \\ A_{22} &= l^2 c_{66} + m^2 c_{22} + n^2 c_{44} + 2mnc_{24} + 2nlc_{46} + 2lmc_{26} \\ A_{33} &= l^2 c_{55} + m^2 c_{44} + n^2 c_{33} + 2mnc_{34} + 2nlc_{35} + 2lmc_{45} \\ A_{23} &= l^2 c_{56} + m^2 c_{24} + n^2 c_{34} + mn(c_{25} + c_{44}) + nl(c_{45} + c_{36}) + lm(c_{46} + c_{25}) \\ A_{31} &= l^2 c_{15} + m^2 c_{46} + n^2 c_{35} + mn(c_{45} + c_{36}) + nl(c_{31} + c_{55}) + lm(c_{56} + c_{14}) \\ A_{12} &= l^2 c_{16} + m^2 c_{26} + n^2 c_{45} + mn(c_{46} + c_{25}) + nl(c_{56} + c_{14}) + lm(c_{12} + c_{66}) \end{aligned} \right\} \quad (12)$$

c_{ik} are the elastic constants and l, m, n are the direction cosines of the elastic wave normal \vec{R}_e .

In order to calculate the direction cosines of the vibration direction ξ_e , viz., $\alpha_e, \beta_e, \gamma_e$, we have to solve the following equations:—

$$\left. \begin{aligned} (A_{11}-q_e)\alpha_e + A_{12}\beta_e + A_{13}\gamma_e &= 0 \\ A_{12}\alpha_e + (A_{22}-q_e)\beta_e + A_{23}\gamma_e &= 0 \\ A_{13}\alpha_e + A_{23}\beta_e + (A_{33}-q_e)\gamma_e &= 0 \end{aligned} \right\} \quad \dots \quad (13)$$

with the additional condition

$$\alpha_e^2 + \beta_e^2 + \gamma_e^2 = 1 \quad \dots \quad (14)$$

Each of the three displacements, which we shall call ξ_1, ξ_2, ξ_3 , of the three waves (see Fig. 1) with stiffness coefficients q_1, q_2, q_3 has in general components both normal and parallel to \vec{R}_e . Thus no one of the waves, in general, is purely longitudinal or purely transverse. However, the wave having the greatest value for q_e has the vibration direction $\vec{\xi}_e$ nearest to the direction of propagation \vec{R}_e and may be called quasi-longitudinal (l) and the other two may be called quasi-transverse (t).

5. DISPLACEMENT AND STRAIN COMPONENTS.

We have for the displacement components u_x, u_y, u_z

$$\left. \begin{aligned} u_x &= \alpha_e \xi_e \sin 2\pi(r - v_e t)/\lambda_e \\ u_y &= \beta_e \xi_e \sin 2\pi(r - v_e t)/\lambda_e \\ u_z &= \gamma_e \xi_e \sin 2\pi(r - v_e t)/\lambda_e \end{aligned} \right\} \quad \dots \quad (15)$$

where

$$r = lx + my + nz \quad \dots \quad (16)$$

The strains are given by

$$\left. \begin{aligned} x_x &= \frac{\partial u_x}{\partial x}; \quad y_y = \frac{\partial u_y}{\partial y}; \quad z_z = \frac{\partial u_z}{\partial z} \\ y_z &= \frac{\partial u_z}{\partial y} + \frac{\partial u_y}{\partial z}; \quad z_x = \frac{\partial u_x}{\partial z} + \frac{\partial u_z}{\partial x}; \quad x_y = \frac{\partial u_y}{\partial x} + \frac{\partial u_x}{\partial y} \end{aligned} \right\} \quad \dots \quad (17)$$

The sine function in (15) contains the frequency factor v_e/λ_e . Therefore the strains and hence the refractive indices fluctuate with that frequency. This shows that the frequency of the elastic wave determines the frequency shift of the scattered light.

6. PHOTOELASTIC EFFECTS OF THE ELASTIC WAVES.

Consider now the changes produced in the optical dielectric tensor by an elastic wave of amplitude $A = 1/R_e = \lambda_e/2\pi$. From (16) and (17) the strains due to this wave are given by the equation below where the sine term has been left out

$$\begin{aligned} x_e &= \alpha_e l, & y_e &= \beta_e m, & z_e &= \gamma_e n & \dots & \dots & \dots & (18) \\ y_e &= (\beta_e n + \gamma_e m), & z_e &= (\gamma_e l + \alpha_e n), & x_e &= (\alpha_e m + \beta_e l) \end{aligned}$$

We now proceed to calculate the changes in the optical polarisability tensor, produced by these strains. Since the wavelength of the elastic waves are of the order of magnitude of the wavelength of light, the macroscopic laws of photoelasticity for the calculation of the tensor components are valid. According to the phenomenological theory of photoelasticity (Pockels, 1906) if a'_{xx} , a'_{yy} , a'_{zz} , a'_{yz} , a'_{zx} and a'_{xy} are the optical polarisation constants of a deformed crystal referred to an arbitrarily chosen co-ordinate system $OXYZ$ and if the original values of these are denoted without the superscript, we have

$$\left. \begin{aligned} a'_{xx} - a_{xx} &= \Delta a_{xx} = p_{11}x_e + p_{12}y_e + p_{13}z_e + p_{14}y_e + p_{15}z_e + p_{16}x_e \\ &\vdots \\ a'_{yz} - a_{yz} &= \Delta a_{yz} = p_{41}x_e + p_{42}y_e + p_{43}z_e + p_{44}y_e + p_{45}z_e + p_{46}x_e \\ &\vdots \end{aligned} \right\} \dots \quad (19)$$

where p_{ik} are called the elasto-optic constants and $p_{ij} \neq p_{ji}$ in general. Since the optical polarisation tensor $[a]$ and the optical dielectric tensor $[\epsilon]$ are reciprocals of each other, their components are related by the equations.

$$\epsilon_{ij} = A_{ij}/D \quad \dots \quad \dots \quad \dots \quad \dots \quad (20)$$

where $D = |[a_{ij}]|$ and A_{ij} is the co-factor of a_{ij} in the determinant D . Writing explicitly

$$D = \begin{vmatrix} a_{xx} & a_{xy} & a_{xz} \\ a_{xy} & a_{yy} & a_{yz} \\ a_{xz} & a_{yz} & a_{zz} \end{vmatrix} \quad \dots \quad \dots \quad \dots \quad \dots \quad (21)$$

If we choose the axes OX , OY and OZ parallel to the principal axes of the optical polarisability ellipsoid (either Fresnel ellipsoid or the indicatrix), the ϵ_{ij} 's ($i \neq j$) vanish and

$$D = \begin{vmatrix} a_{xx} & 0 & 0 \\ 0 & a_{yy} & 0 \\ 0 & 0 & a_{zz} \end{vmatrix} = a_{xx}a_{yy}a_{zz} \quad \dots \quad \dots \quad \dots \quad (22)$$

(choosing the axes parallel to the polarisability ellipsoid will conform with the axes used by Voigt in crystal elasticity except for the monoclinic and the triclinic systems. For crystals belonging to these systems the photoelastic behaviour has not been studied so far in any actual case. Hence the distinction mentioned is unimportant).

$$\text{Let } a_{xx} = a_{11}, \quad a_{yy} = a_{22}, \quad a_{zz} = a_{33}$$

Therefore, from (20) and (22)

$$\left. \begin{aligned} \epsilon_{xx} &= a_{yy} \cdot a_{zz} / a_{xx} \cdot a_{yy} \cdot a_{zz} = 1/a_{xx} = 1/a_{11} \\ \epsilon_{yy} &= 1/a_{22} \\ \epsilon_{zz} &= 1/a_{33} \end{aligned} \right\} \quad \dots \quad (23)$$

and

$$\epsilon_{yz} = \epsilon_{zx} = \epsilon_{xy} = 0$$

However, when the crystal is deformed none of the components, in general, is zero. We have, therefore,

$$\epsilon'_{ij} = A'_{ij}/D' \quad \dots \quad (24)$$

Then the changes $\Delta\epsilon_{ij} = \epsilon'_{ij} - \epsilon_{ij}$ can be calculated in terms of the corresponding Δa_{ij} 's if we neglect the second and higher order terms. These changes are given by

$$\left. \begin{aligned} \Delta\epsilon_{xx} &= -\Delta a_{xx}/a_{xx}^2 - \Delta a_{xx}/a_{11}^2 \\ \Delta\epsilon_{yy} &= -\Delta a_{yy}/a_{22}^2 \\ \Delta\epsilon_{zz} &= -\Delta a_{zz}/a_{33}^2 \end{aligned} \right\} \quad \dots \quad (25)$$

$$\begin{aligned} \Delta\epsilon_{yz} &= -\Delta a_{yz}/a_{22} \cdot a_{33}; \quad \Delta\epsilon_{zx} = -\Delta a_{zx}/a_{33} \cdot a_{11} \\ \Delta\epsilon_{xy} &= -\Delta a_{xy}/a_{11} \cdot a_{22} \end{aligned}$$

Since the principal optical dielectric constants are the squares of the corresponding refractive indices n_1, n_2, n_3 , we have from (25)

$$\left. \begin{aligned} \Delta\epsilon_{xx} &= -n_1^4 \Delta a_{xx}; \quad \Delta\epsilon_{yy} = -n_2^4 \Delta a_{yy}; \quad \Delta\epsilon_{zz} = -n_3^4 \Delta a_{zz} \\ \Delta\epsilon_{yz} &= -n_2^2 n_3^2 \Delta a_{yz}; \quad \Delta\epsilon_{zx} = -n_3^2 n_1^2 \Delta a_{zx}; \quad \Delta\epsilon_{xy} = -n_1^2 n_2^2 \Delta a_{xy} \end{aligned} \right\} \quad (26)$$

Knowing the strains from (18), $[\Delta\epsilon]_A^P$ etc. can be calculated using equations (19) and (26). If this value be substituted in equations (10), we get the intensities of the various components leaving out the constant factor $\pi^2 kT/2\lambda^4$.

7. METHOD OF EVALUATION OF THE INTENSITIES.

In any specific case, the first step is to find the polarisation characteristics and the directions of the elastic wave normal for each of the four species. This can be done as shown in article 8 of Part III. Next the stiffness coefficients q_s and the direction cosines ($\alpha_s, \beta_s, \gamma_s$) of the vibration directions ξ_s of the three elastic waves in each species are calculated using Christoffel's equations (11) and the known elastic constants of the crystal. Using equation (15) the components of the strain can be calculated. Putting these in equations (19) and (26) we get the tensor $[\Delta\epsilon]$, knowing the photoelastic constants and the principal refractive indices. Since the polarisation characteristics, i.e., the vectors $\vec{P}, \vec{Q}, \vec{A}, \vec{B}$ are known, $D_I^S(R_s)$ can then be evaluated from equations (7). Substituting these in the equations (10) the intensities of the various components are obtained.

8. SPECIAL CASE.

As an illustration of the above method, we consider the particular case of backward scattering along the normal to the cleavage face of calcite. This direction is almost at 45° to Y and Z in the plane YZ and in Voigt's definition of axes of reference for elastic constants it is in the positive quadrant of OY and OZ . It may be designated $YZ(-45^\circ)$. We shall make our calculations for the exact 45° direction.

The states of polarisation of the incident and the scattered waves are: $\vec{A} = \vec{P} = OX$; $\vec{B} = \vec{Q} = YZ(-45^\circ)$. The directions of propagation of the elastic wave effective in the scattering of all the species of the Doppler components also coincides with $YZ(+45^\circ)$ since the scattering is along the exact backward direction. Consequently,

$$q_1 = q_4 = q_7 = q_{10}, \quad q_2 = q_5 = q_8 = q_{11}, \quad q_3 = q_6 = q_9 = q_{12} \quad \dots \quad (27)$$

and $l = 0$, $m = 1/\sqrt{2}$, $n = 1/\sqrt{2}$

In the case of calcite, the schemes for the elastic and elasto-optic constants are given by

c_{11}	c_{12}	c_{13}	c_{14}	0	0	p_{11}	p_{12}	p_{13}	p_{14}	0	0
c_{12}	c_{11}	c_{13}	$-c_{14}$	0	0	p_{12}	p_{11}	p_{13}	$-p_{14}$	0	0
c_{13}	c_{13}	c_{33}	0	0	0	p_{31}	p_{31}	p_{33}	0	0	0
c_{14}	$-c_{14}$	0	c_{44}	0	0	p_{41}	$-p_{41}$	0	p_{44}	0	0
0	0	0	0	c_{44}	c_{14}	0	0	0	0	p_{44}	$-p_{41}$
0	0	0	0	c_{14}	$\frac{1}{2}(c_{11}-c_{12})$	0	0	0	0	p_{14}	$\frac{1}{2}(p_{11}-p_{12})$

where Voigt's values (Cady, 1946) for c_{ik} in 10^{11} dynes/cm.² and Pockels values for p_{ik} (I.C.T.) are

$$\begin{aligned} c_{11} &= 13.71; & c_{33} &= 7.97; & c_{12} &= 4.56; & c_{13} &= 4.51; & c_{14} &= -2.08; \\ c_{44} &= 3.42; & c_{66} &= 4.58; \\ p_{11} &= 0.095; & p_{33} &= 0.178; & p_{12} &= 0.189; & p_{13} &= 0.215; & p_{31} &= 0.304; \\ p_{14} &= -0.006; & p_{41} &= 0.010; & p_{44} &= -0.090; & p_{66} &= -0.047. \end{aligned}$$

$$n_1 = n_2 = n_\omega = 1.765 \text{ and } n_3 = n_e = 1.532 \text{ for } \lambda 2537.$$

$$\text{Let } n_1/n_3 = r. \text{ Then } r = 1.152 \quad \dots \quad (30)$$

In equations (26) it is convenient to take out the factor $(n_3)^4$ and introduce quantities p'_{ik} given by (neglecting sign)

$$\begin{aligned} p'_{11} &= p_{11}r^4 = 0.1672; & p'_{33} &= p_{33} = 0.178; & p'_{12} &= p_{12}r^4 = 0.3328; \\ p'_{13} &= p_{13}r^4 = 0.3378; & p'_{31} &= p_{31} = 0.3091; & p'_{14} &= p_{14}r^4 = 0.01056; \\ p'_{41} &= p_{41}r^2 = 0.01326; & p'_{44} &= p_{44}r^2 = 0.1194; & p'_{66} &= p_{66}r^2 = 0.0827 \end{aligned}$$

In equations (12) we have

$$\begin{aligned} A_{11} &= (c_{66} + c_{44} + 2c_{14})/2 = 1.92 \\ A_{22} &= (c_{11} + c_{44} - 2c_{14})/2 = 10.65 \\ A_{33} &= (c_{44} + c_{33})/2 = 5.695 \\ A_{23} &= (-c_{14} + c_{13} + c_{44})/2 = 5.005 \\ A_{31} &= A_{12} = 0 \end{aligned}$$

Solving the determinantal equation (11) for q_1, q_2, q_3 and substituting in equations (13) and (14) for α, β, γ we have

$$\left. \begin{aligned} q_1 &= 1.92 \times 10^{11} \text{ dynes/cm.}^2; & \alpha_1 &= 1, \beta_1 = 0, & \gamma_1 &= 0 \\ q_2 &= 13.76 \times 10^{11} \text{ dynes/cm.}^2; & \alpha_2 &= 0, \beta_2 = 0.8494, & \gamma_2 &= 0.5277 \\ q_3 &= 2.58 \times 10^{11} \text{ dynes/cm.}^2; & \alpha_3 &= 0, \beta_3 = 0.5277, & \gamma_3 &= 0.8494 \end{aligned} \right\} \dots \quad (33)$$

using $\rho = 2.704 \text{ gm./c.c. (I.C.T.)}$

The shifts of the different species in cm.^{-1} are given below.

TABLE I.

Species	Wave 2	Wave 3	Wave 1
P_A	3.31	1.43	1.24
P_B	3.19	1.39	1.19
Q_A	3.19	1.38	1.19
Q_B	3.06	1.31	1.15

Wave 1 is a transverse wave with vibration direction parallel to the X -axis while the other two are quasi-longitudinal and quasi-transverse waves with the vibration directions in the plane YZ .

For wave 1, the non-vanishing strains are from equations (18) $z_x = x_y = 1/\sqrt{2}$ and hence the non-vanishing tensor components are (leaving out the factor n_3^4) from (26) and (19)

$$\left. \begin{aligned} \Delta \epsilon_{xx} &= (p'_{44} - p'_{41})/\sqrt{2} = -0.1061/\sqrt{2} \\ \Delta \epsilon_{yy} &= (p'_{14} + p'_{66})/\sqrt{2} = -0.0933/\sqrt{2} \end{aligned} \right\} \quad \dots \quad (35)$$

As mentioned before, the states of polarisation of the incident and of the scattered waves are in particular $\vec{A} = \vec{P} = OX$, $\vec{B} = \vec{Q} = YZ(-45^\circ)$. Thus the direction cosines of these two vectors are $(1, 0, 0)$ and $(0, 1/\sqrt{2}, -1/\sqrt{2})$. Then from equations (10) and (33)

$$\begin{aligned} {}_1I_A^P &= {}_1I_B^Q = 0 \text{ for } 1.24 \text{ cm.}^{-1} \text{ and } 1.15 \text{ cm.}^{-1} \text{ components} \\ {}_1I_A^Q &= {}_1I_B^P = \frac{\pi^2 n_3^8 k T (\Delta \epsilon_{xx} - \Delta \epsilon_{yy})^2}{2\lambda^4 2q_1} = 0.0213 \times 10^{-14} \times \text{constant.} \end{aligned}$$

For the other two waves 2 and 3 we have

$$x_x = z_x = x_y = 0, \quad y_y = (1/\sqrt{2})\beta, \quad z_z = (1/\sqrt{2})\gamma, \quad y_z = (1/\sqrt{2})(\beta + \gamma).$$

The values of the components $\Delta \epsilon_{ij}$ are given in the table below.

TABLE II.

$\Delta \epsilon_{ij}$	Formula	Wave 2	Wave 3
$\Delta \epsilon_{xx} =$	$\frac{p'_{12}\beta + p'_{13}\gamma + p'_{14}(\beta + \gamma)}{\sqrt{2}}$	$\frac{0.4678}{\sqrt{2}}$	$\frac{0.1405}{\sqrt{2}}$
$\Delta \epsilon_{yy} =$	$\frac{p'_{11}\beta + p'_{13}\gamma - p'_{14}(\beta + \gamma)}{\sqrt{2}}$	$\frac{0.3562}{\sqrt{2}}$	$\frac{0.2367}{\sqrt{2}}$
$\Delta \epsilon_{zz} =$	$\frac{p'_{31}\beta + p'_{33}\gamma}{\sqrt{2}}$	$\frac{0.3564}{\sqrt{2}}$	$\frac{0.0110}{\sqrt{2}}$
$\Delta \epsilon_{yz} =$	$\frac{p'_{41}\beta + p'_{44}(\beta + \gamma)}{\sqrt{2}}$	$\frac{0.0743}{\sqrt{2}}$	$\frac{0.0314}{\sqrt{2}}$
$\Delta \epsilon_{xx} = \Delta \epsilon_{yy} =$	0	0	0

Hence

$${}_2I_A^P = 7.95 \times 10^{-11} \text{ for } \Delta\nu = 3.31 \text{ cm.}^{-1}$$

$${}_3I_A^P = 3.83 \times 10^{-11} \text{ for } \Delta\nu = 1.43 \text{ cm.}^{-1}$$

$${}_2I_B^P = {}_3I_B^P = {}_2I_A^Q = {}_3I_B^Q = 0 \text{ for } \Delta\nu = 3.16, 1.39, 3.16, 1.39 \text{ cm.}^{-1}$$

$${}_2I_B^Q = 6.74 \times 10^{-11} \text{ for } \Delta\nu = 3.16 \text{ cm.}^{-1}$$

$${}_3I_B^Q = 1.27 \times 10^{-11} \text{ for } \Delta\nu = 1.32 \text{ cm.}^{-1}$$

The results are indicated schematically in Fig. 2 (the symbols Σ , σ , Π and π are used instead of P , A , Q and B respectively since we are considering the backward scattering in a uniaxial crystal and Σ , σ refer to the ordinary and Π and π to the extraordinary light waves (cf. Part III)). A dotted line corresponds to a Doppler component of zero intensity while the heights of the lines have been made proportional to the intensity of the others.

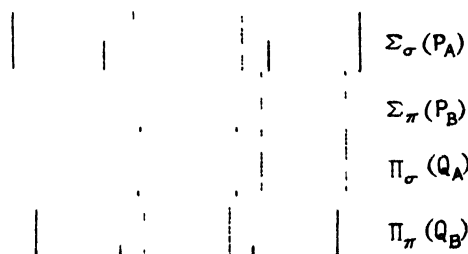


FIG. 2.

We see that for the transverse wave (1) only one pair of distinct Doppler components should have finite intensity while for the other two waves (2) and (3), the two pairs of Doppler components should be capable of observation.

The results of the calculation for five (including $yz+45^\circ$) different cases of backward scattering are collectively given in Table III. The values of the intensities given are only relative, the absolute values being obtained by multiplying with the factor

$$\pi^2 k T n_s^4 2\lambda^4 = 1.49 \times 10^7$$

In the case of forward scattering for the species having finite shifts, say Q_A and P_B , the effective elastic wave normal coincides with the direction of propagation of the light wave and is therefore the same as for backward scattering. Consequently, the values of the intensities for these species given in Table III also hold for forward scattering. Only the shifts are different and these shifts will have to be calculated by putting $(n_s - n_e)$ instead of $(n_e + n_s)$ in equation (18) of Part III.

9. DISCUSSION.

Since the optic axis of calcite is the direction of single wave velocity for light, all the four species have the same frequency shift in backward scattering along this direction. Further, the two transverse elastic waves have the same velocity and hence there can only be two pairs of Doppler components. For the longitudinal wave only the strain z_z is finite. Hence from (19), $\Delta a_{yz} = \Delta a_{xz} = \Delta a_{xy} = 0$. Consequently, the Doppler components arising from this wave should be polarised in the same way as in the incident wave. On the other hand, for the transverse waves y_z and z_x are finite and from (19) $\Delta a_{xx} = \Delta a_{yy} = \Delta a_{zz} = 0$, i.e., the optical indicatrix only rotates without any change in the principal values. Consequently,

TABLE III.
Backward Scattering in Calcite.

Direction of wave normal	Effective elastic constant $q \times 10^{-11}$ dynes/cm. ²	Vibration direction		Velocity $\sqrt{q/\rho}$ metres/sec.	P_A		Q_B		P_B and Q_A		$I = \Sigma I_A^P \times 10^{14}$	Total intensity
		α, β, γ			Doppler Sepn. $\Delta\nu$ in cm. ⁻¹	Intensity	Doppler Sepn. $\Delta\nu$ in cm. ⁻¹	Intensity	Doppler Sepn. $\Delta\nu$ in cm. ⁻¹	Intensity		
1 (Z) 0, 0, 1 $\vec{P} = \vec{A} = OY$	7.97 3.42 } 3.42 }	0, 0, 1 1, 0, 0 0, 1, 0	1 0 0	5.430 3.556 3.556	2.518 1.052 1.052	17.97 0.0 0.033	2.518 1.052 1.052	17.97 0 0.033	2.518 1.052 1.052	0.0 0.033 0	35.94 0.065 0.065	36.07
2 (X) 1, 0, 0 $\vec{P} = \vec{A} = OZ$	13.71 6.16 1.84	1, 0, 0 0, 0.80, 0 0, 0.61, 0.80	0 0.61 0.80	7.120 4.773 2.608	2.866 1.922 1.050	6.97 0 0	3.301 2.213 1.210	8.08 0 0	3.083 2.067 1.130	0.01 0 0	15.07 0 0	15.07
3 (Y) 0, 1, 0 $\vec{P} = \vec{A} = OX$	14.12 4.58 3.02	0, 0.98, 0 1, 0, 0 0, 0.19, 0.98	0.19 0 0.98	7.126 4.116 3.342	3.351 1.908 1.550	7.46 0 1.81	2.909 1.657 1.345	6.52 0 1.15	3.130 1.782 1.448	0 0.038 0	13.98 0.08 2.96	17.02
4 (YZ 45°) 0, 1/√2, 1/√2 $\vec{P} = \vec{A} = OX$	13.76 2.58 1.92	0, 0.5, 0.53 1, 0, 0 0, 0.53, 0.85	0.53 0 0.85	7.134 3.089 2.665	3.308 1.432 1.236	7.95 3.83 0	3.064 1.326 1.145	6.74 1.27 0	3.185 1.379 1.190	0 0 0.021	14.69 5.10 0.04	19.83
5 (YZ-45°) 0, 1/√2, -1/√2 $\vec{P} = \vec{A} = OX$	9.04 6.08 3.14	0, 0.75, -0.66 1, 0, 0 0, 0.66, 0.75	-0.66 0 0.75	5.782 4.714 3.408	2.681 2.186 1.550	14.64 0 0.72	2.484 2.025 1.436	14.62 0 0.85	2.582 2.106 1.493	0 0.15 0	29.26 0.30 1.51	31.13

if circularly polarised light is used, the transverse components should be polarised circularly with the sense of rotation opposite to that of the incident wave.

In the backward scattering along the X-axis neither of the transverse waves can give rise to any scattering while only two of the species arising from the longitudinal elastic waves should be present (case 2, Table III). Since the difference between the refractive indices n_1 and n_3 is largest in this case, the separation between these two pairs should be greatest. Thus this case is ideal for testing the theory given for calculating the intensities and also for demonstrating the effect of birefringence on the splitting of the Doppler components.

10. QUARTZ.

Since the birefringence of quartz even at λ 2537 is negligibly small ($n_e - n_o = 0.01$), the four species of Doppler components have nearly the same frequency shifts. The calculated intensities for 7 cases of backward scattering and 10 cases of transverse scattering are presented respectively in Tables V and VI. The values of elastic (Voigt, Koga, 1936) and elasto-optic (I.C.T.) constants of quartz used are given below and the vibration directions of the various elastic waves for different directions of propagation are given in Table IV. The convention for the sign and directions of the axes of reference follows that of Voigt both for the description of elastic as well as photoelastic behaviour. The trigonal axis is chosen as the Z-axis, either end being positive. The Y-axis is the projection of any one of the rhombohedral

TABLE IV.

Vibration Directions of the Elastic Waves in Quartz.

No.	Direction of wave normal l, m, n	Effective elastic constant $q \times 10^{-11}$	Vibration direction		
			α	β	γ
1	Z 0, 0, 1 ..	10.567	0	0	1
		5.709	1	0	0
		5.709	0	1	0
2	X 1, 0, 0 ..	8.545	1	0	0
		6.722	0	0.5294	0.8483
		2.898	0	0.8483	-0.5293
3	Y 0, 1, 0 ..	9.322	0	0.9063	-0.4226
		4.922	0	0.4226	0.9063
		3.910	1	0	0
4	YZ (+45) 0, $\frac{1}{\sqrt{2}}, \frac{1}{\sqrt{2}}$..	9.833	0	0.5289	0.8493
		6.497	1	0	0
		3.745	0	-0.8493	0.5289
5	YZ (-45) 0, $\frac{1}{\sqrt{2}}, -\frac{1}{\sqrt{2}}$..	12.906	0	-0.7337	0.6794
		4.046	0	-0.6794	-0.7337
		3.123	1	0	0
6	ZX (+45) $\frac{1}{\sqrt{2}}, 0, \frac{1}{\sqrt{2}}$..	11.687	0.6530	0.2484	0.7155
		4.913	0.3277	0.7603	-0.5604
		3.474	-0.6826	0.6031	0.4123
7	XY (+45) $\frac{1}{\sqrt{2}}, \frac{1}{\sqrt{2}}, 0$..	9.017	0.7160	0.5944	0.3659
		5.890	0.0854	-0.5912	0.8021
		3.257	0.6927	-0.5410	-0.4772

Millerian axes upon a plane normal to the Z -axis, its positive direction being drawn outwards from one of the major rhomb faces R at the positive end of the Z -axis. These definitions are valid both for left and right crystals. The X -axis is chosen normal to these. According to Voigt it forms always a right-handed system with the other two, while for convenience of describing piezoelectric properties the positive direction forms a left-handed system for left crystals, according to the latest I.R.E.* axial system (Cady, p. 40). But in the description of centrosymmetrical properties, like elastic and photoelastic behaviour, the sense of the X -axis is irrelevant. It may be noted that in Table IV the sign of the vibration directions of the elastic waves for X -cut and Y -cut crystals are opposite to those given in Cady's book (p. 140). This is because of an error in Cady's book which has been accepted by Prof. Cady in a private correspondence.

$$\rho = 2.66 \text{ gm./c.c.}, n_{\omega} = 1.598, n_{\epsilon} = 1.609, \lambda = 2537 \text{ \AA.}$$

$$\text{Voigt (Koga) adiabatic elastic constants in } 10^{11} \text{ dynes/cm.}^2$$

$$c_{11} = 8.545, c_{12} = 0.726, c_{13} = 1.437, c_{14} = 1.687, c_{33} = 10.567,$$

$$c_{44} = 5.709, c_{66} = (c_{11} - c_{12})/2 = 3.910$$

$$p_{11} = 0.138, p_{12} = 0.250, p_{13} = 0.259, p_{14} = 0.029, p_{31} = 0.258,$$

$$p_{33} = 0.098, p_{41} = -0.042, p_{44} = -0.069, p_{66} = -0.056$$

$$\pi^2 n^3 k T / 2 \lambda^4 = 2.09 \times 10^7$$

TABLE V.

Backward Scattering in Quartz.

No.	Direction of wave normal	Effective elastic constant $q \times 10^{-11}$	Brillouin Sepn. in cm.^{-1}	I_A^P	I_B^Q	$I_A^Q = I_B^P$	$I = \Sigma I_A^P \times 10^{-14}$	Total intensity $\times 10^{-14}$
1	OZ $\vec{P} = \vec{A} = OX$ or OY	10.567 5.709 5.709	2.646 1.945 1.945	6.350 0.147 0	6.350 0.147 0	0 0 0.147	12.700 0 0.589	13.289
2	OX $\vec{P} = \vec{A} = OZ$	8.545 6.722 2.898	2.380 2.111 1.387	7.787 0 0	7.313 0 0	0.207 0 0	15.524 0 0	15.524
3	OY $\vec{P} = \vec{A} = OX$	9.322 4.922 3.910	2.486 1.808 1.612	6.125 1.269 0	5.875 2.400 0	0 0 0.417	11.998 3.699 0.902	16.569
4	$YZ (+45^\circ)$ $\vec{P} = \vec{A} = OX$	9.833 6.497 3.745	2.554 2.075 1.575	4.958 0 0.582	3.704 0 0.562	0 0.026 0	8.662 0.052 1.144	9.858
5	$YZ (-45^\circ)$ $\vec{P} = \vec{A} = OX$	12.906 4.046 3.123	2.925 1.638 1.439	3.931 0.058 0	1.119 0.105 0	0 0 0	5.050 0.164 0.0	5.214
6	$ZX (\pm 45^\circ)$ $\vec{P} = \vec{A} = OY$	11.687 4.913 3.474	2.784 2.805 1.517	5.299 0.099 0.310	10.110 1.728 0.856	0.002 0.047 0.012	15.418 1.874 1.178	18.463
7	$XY (\pm 45^\circ)$ $\vec{P} = \vec{A} = OZ$	9.017 5.890 3.257	2.444 1.976 1.469	6.340 1.445 0.235	6.340 0.904 0.089	0.069 0.102 0.159	12.819 2.553 0.642	16.014

TABLE VI.
Transverse Scattering in Quartz.

No.	Plane of scattering	R_e	$q \times 10^{-11}$	Brillouin Sepn. $\Delta\nu$ in cm.^{-1}	I_A^P	I_B^Q	I_A^Q	I_B^P	$I = \Sigma I^P$ $\times 10^{14}$	Total intensity $\times 10^{14}$
1	YOZ .. $\vec{P} = \vec{A} = \text{OX}$	..	10.567 5.709 } 5.709 }	1.872 1.376 } 1.376 }	6.350 0.147 0	0.613 0.037 0	0 0 0.140	0 0 0.841	6.963 1.165	8.128
2	YOZ .. $\vec{P} = \vec{A} = \text{OX}$	..	12.906 4.046 3.123	2.068 1.158 1.017	3.931 0.058 0	0.175 0.070 0	0 0 0.117	0 0 0.117	4.106 0.128 0.234	4.468
3	YOZ .. $\vec{P} = \vec{A} = \text{OX}$	..	9.322 4.922 3.910	1.758 1.278 1.140	6.125 1.269 0	1.573 0.120 0	0 0 0.025	0 0 1.228	7.708 1.389 1.253	10.350
4	YOZ .. $\vec{P} = \vec{A} = \text{OX}$	..	9.833 6.497 3.745	1.805 1.468 1.114	4.958 0 0.582	0.270 0 0.025	0 0.558 0	0 0.948 0	5.228 1.504 0.606	7.338
5	ZOX .. $\vec{P} = \vec{A} = \text{OY}$	..	8.545 6.722 2.898	1.683 1.493 0.980	7.313 0 0	0.421 0 0	0.104 0.219 0.225	0.104 0.219 0.225	7.941 0.438 0.449	8.828
6	ZOX .. $\vec{P} = \vec{A} = \text{OY}$	..	11.687 4.913 3.474	1.968 1.277 1.073	5.299 0.099 0.310	0.364 0.277 0.019	0.252 0.063 0.001	0.123 0.132 0.096	6.038 0.571 0.426	7.035
7	ZOX .. $\vec{P} = \vec{A} = \text{OY}$	..	10.567 5.709 } 5.709 }	1.872 1.376 } 1.376 }	6.350 0.147 0	0.613 0.037 0	0 0.417 0.074	0 0.417 0.074	6.963 1.165	8.128
8'	XOY .. $\vec{P} = \vec{A} = \text{OZ}$	..	9.322 4.922 3.910	1.758 1.278 1.140	5.873 2.400 0	0.426 0.001 0	0.485 0.409 0.226	0.485 0.409 0.226	7.269 3.219 0.451	10.939
9	XOY .. $\vec{P} = \vec{A} = \text{OZ}$	..	9.017 5.890 3.257	1.729 1.397 1.039	6.340 1.445 0.235	0.391 0.002 0.004	0.351 0.099 0.108	0.051 0.595 0.055	7.140 2.141 0.403	9.684
10	XOY .. $\vec{P} = \vec{A} = \text{OZ}$	..	8.545 6.772 2.898	1.683 1.493 0.980	7.787 0 0	0.367 0 0	0.104 0 0.000	0.104 0.485 0.001	8.361 0.970 0.001	9.332

11. DISCUSSION.

As is well known, quartz exhibits the greatest changes in elastic properties in the YZ plane, the maximum and minimum values of Young's modulus occurring at $48^\circ 36'$ ($Y = 130.8 \times 10^{11}$ dynes/cm.²) and $71^\circ 4'$ ($Y = 70.3 \times 10^{11}$ dynes/cm.²). Thus the properties are different for $YZ(+45^\circ)$ and $YZ(-45^\circ)$. Hence the case in which the light is incident along OY and scattered along OZ (case 4 of Table VI) would be different from light being incident along OY and scattered along OZ (case 2). The actual verification of this has already been reported (see Table I of Part I) (Krishnan and Chandrasekharan, 1950). Matossi (1934) in his calculations of the total intensity of scattering for various directions has obviously overlooked this very important factor. For XY and XZ planes these differences do not exist since the X -axis is a two-fold axis of symmetry for this crystal.

A perusal of Table VI shows that for incident unpolarised light, the value of depolarisation defined in the usual way, for transverse scattering $(Q_A + Q_B)/(P_A + P_B)$, which is very small, being only of the order of 10%. It is also seen from Tables V and VI that in general the intensities of the transverse Doppler components are less than 15% of the longitudinal ones. This is in general accord with the experimental observation (Part I) that only the longitudinal Doppler components are recorded, showing thereby that, comparatively, the transverse ones are of feeble intensity. For certain cases, however, like backward scattering along Y one should expect the transverse components with an appreciable intensity of about $\frac{1}{3}$ of the longitudinal one. Although this case was studied the transverse components could not be recorded before the faint wings of the unabsorbed λ 2537 radiation are recorded and the result is inconclusive and more work has to be done.

ACKNOWLEDGEMENTS.

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SUMMARY.

The theory of thermal scattering of light in birefringent solids (Chandrasekharan, 1951) shows that there are 12 pairs of Doppler components. Their intensities have been individually evaluated following a reasoning similar to that of Mueller (1938) for amorphous solid. For specific crystal orientations the intensities have been calculated in the case of calcite (5) and of quartz (17) using the known elastic and photoelastic constants.

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KARYO-SYSTEMATIC STUDIES IN HELOBIALES.

I. BUTOMACEAE

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I. INTRODUCTION.

Butomaceae is a small family consisting of five genera,¹ namely *Tenagocharis*, *Hydrocleis*, *Limnocharis*, *Butomus* and *Ostenia*, which are aquatic and marsh herbs. The family is characterised by a distinct biseriate perianth, which is typically dicotyledonous but for the 3-merous condition, numerous stamens, an apocarpous pistil and numerous ovules, which are scattered all over the inner surface of the free carpels.

The family belongs to the order Helobiales or Reihe Helobiac² of Engler and Prantl (1889) and has assumed great importance in the more recent systems of classification. For instance, Hutchinson (1934) considers it as one of the most ancient families of the monocotyledons, finding its dicotyledonous counterpart in Cabombaceae of Ranales, which it resembles in the peculiar type of placentation. In Hutchinson's system it enjoys a pre-eminent position as a representative of ancestral progenitors of the liliaceous stocks. Johri (1935 and 1936) working on the embryology of the family found pollen grains in the stylar canal of *Tenagocharis*

¹ If the monotypic and endemic genus *Elattosis* of Tonkin is included (Lawrence, 1951), the number becomes six.

² This order is also known as the Najadales and the Fluviales.

latifolia, simulating a condition in some of the Gymnosperms (Sahni, 1936) and in the ovary cavity of *Butomus umbellatus* (Johri, 1936). This affords additional evidence in favour of the views of Hutchinson (*loc. cit.*). That the family is primitive was also recognised by Buchenau (1903), who, however, placed it phylogenetically next to Alismataceae.

The cytological literature that is available on the family shows that all the previous work is confined only to a few reports of chromosome numbers (vide Table I) and none of the previous authors has attempted a critical study of the karyotypes of the different genera. It is now increasingly realised that a knowledge of the karyotypes is indispensable for precisely determining the genetic-evolutionary processes within a family. This has been shown by Davie (1934) in Malvaceae, by Flory (1936) in Gymnosperms, by Phillips (1938) in Plumbaginaceae, by Baldwin (1940) in Crassulaceae, by Sugiura (1940a; b) in Plumbaginaceae and Papaveraceae, by Gregory (1941) in Ranunculaceae, by Sato (1942) in Liliaceae and allied families, by Perry (1943) in Euphorbiaceae, by Taylor (1943) in Oleaceae and by Rork (1949) in Gentianaceae. So far no attempt has been made to interpret the phylogenetic relationships of the various genera of Butomaceae in the light of cytology. It was primarily with this object that the present study of mitotic and meiotic stages of four genera was undertaken.

Moreover, as the family is considered primitive on the basis of external morphology, it may not be unreasonable to presume that the karyotypes encountered in the family may represent the starting point for the karyophylysis of Helobiales, if not all the monocotyledons. An investigation of this possibility is the ultimate object of the present investigation.

II. MATERIALS AND METHODS.

The materials for the cytological study of *Tenagocharis* and *Butomus* were collected from different parts of India. The materials of *Hydrocleis nymphoides* and *Limncharis flava* were obtained from the New York Botanical Garden, New York and the Botanic Gardens, Singapore, respectively. The author is indebted to Dr. C. A. Berger, Fordham University, New York and to Mr. J. Sinclair, Curator of the Herbarium, Singapore, for the excellently fixed root-tip materials of the two latter genera. He is also thankful to Dr. J. Robbins, Director, New York Botanical Gardens, for the help rendered in connection with the collection of *Hydrocleis*.

The somatic chromosomes were studied from the root-tips fixed in Benda with and without acetic acid, 2BE, Navashin's chrome-acetic-formalin as modified by Belling and Randolph and Lewitskey's chromic-formalin (1 : 1 and 1 : 2). For the study of meiosis, the schedule recommended by Kihara (1924) gave best results and medium Flemming and Navashin's solutions were employed as fixatives after a pretreatment of the flower buds with Seemanns' Carnoy (1 : 1 : 3). Crystal violet was used as stain.

In genera like *Tenagocharis* and *Hydrocleis*, where the cell size in the somatic tissues is relatively small in comparison with the size of the chromosomes, the study of chromosome morphology was fraught with considerable difficulty. Not only are the chromosomes long and slender but their great foreshortening made it almost impossible to determine the relative lengths of the arms. In these cases, the excised root-tips were pretreated with 0.1 to 0.25% aqueous colchicine solution for 30-40 minutes, washed in running water for about the same time and then fixed in acetic alcohol (1 : 3). Temporary acetocarmine smears of this material prepared in accordance with Warmke's method (1935) gave flat metaphase figures. These were found to be far superior to those observed in the sections stained with crystal violet. In the case of *Limncharis*, the section smear method of Warmke (1946) as modified by Bowden (1949) was applied with a fair degree of success. The excised root-tips, however, were not precooled, as recommended by Bowden.

III. CHROMOSOME NUMBERS IN BUTOMACEAE.

TABLE I.

Genus and species.	n.	2n.	Author.
<i>Tenagocharis latifolia</i> (D. Don.) Buchenau ..	7	..	Sundar Rao, 1946.
" " " "	7	14	This paper.
<i>Hydrocleis nymphoides</i> (Willd.) Buchenau ..	..	12	Suessenguth, 1920.
" " " "	..	16	This paper.
<i>Limnocharis flava</i> (L.) Buchenau ..	10	..	Duhl, 1940.
" " " "	..	20	This paper.
<i>Butomus umbellatus</i> L. ..	11-12	..	Holmgren, 1913.
" " " "	..	16	Liehr, 1916.
" " " "	..	40	Terby, 1922.
" " " "	14 & 20	..	Lohammar, 1931.
" " " "	..	26	Whitaker, 1934.
" " " "	..	26	This paper.

IV. DESCRIPTIONS.

(a) *Tenagocharis latifolia** (D. Don.) Buchenau ($2n = 14$; $n = 7$).

Tenagocharis is a monotypic genus with a discontinuous distribution (Good, 1947). It extends over the whole of tropical Africa, India and the northern part of Australia. Fig. 1 represents the somatic metaphase from the root-tip cells. The 14 chromosomes fall roughly into three groups as regards their size. The haploid set (Fig. 2) consists of—

- (1) three distinctly long chromosomes of almost the same length, two with median (A and C) and the third (B) with submedian constrictions;
- (2) three medium-sized chromosomes which differ but slightly in length from one another; one of them (D) has a distinctly submedian constriction, while the others (E and F) have terminal constrictions;
- (3) one short chromosome (G) with a terminal constriction; this represents the shortest pair in the complement and is satellited.

An examination of the idiogram reveals the size relations between the different types of chromosomes. The satellites are attached to the short proximal arms of the short chromosomes and consist of fine thread-like structures with small terminal knobs. In certain favourable cases (Fig. 1), the SAT-thread of each of the chromatids could be made out. Corresponding to the SAT-chromosomes, there are two nucleoli in the telophases (Fig. 5), which often persist without fusion in the resting nucleus. No variation in the number of nucleoli was encountered either at the telophase or in the resting stages.

In a majority of metaphases, the chromosomes are evenly distributed on the spindle (Fig. 1). When the long chromosomes come to lie at the periphery, as is usually the case, their distal arms lie wholly outside the spindle. This is the most common disposition; but when they arrange themselves within the spindle, the arms of the chromosomes are bent so as to adjust to the limited space of the spindle. It is a matter of considerable interest to note that the several chromosomes have their centromeres lying equidistant from one another on the metaphase, appearing as though they are under mutual repulsion. One metaphase was observed (Fig. 4) where almost all the chromosomes tend to lie round the spindle leaving a small gap

* '*Tenagocharis* Hochst, in *Flora* (June, 1841) *Butomopsis* Kunth. Enum., pl. III (July, 1841).' Cited from Buchenau (1903).

in the centre. In Fig. 3 there is a manifestation of such a tendency, with only four terminally constricted chromosomes in the centre.



FIGS. 1-8. *Tenagocharis latifolia*. Fig. 1. Somatic metaphase showing 14 chromosomes; note two SAT-chromosomes. Fig. 2. Idiogram; chromosome G is satellited. Fig. 3. Somatic metaphase where chromosomes are tending towards a peripheral arrangement. Fig. 4. Somatic metaphase showing the almost peripheral arrangement. Fig. 5. Somatic telophase with two nucleoli in each of the daughter nucleus. Fig. 6. Metaphase I showing 7 bivalents. Fig. 7. An exceptional metaphase I with 8 bivalents. Fig. 8. Anaphase II showing lagging and bridge formation. \times about 2,410.

The presence of three pairs of chromosomes with terminal insertions having small second arms is one of the interesting feature of the karyotype of *Tenagocharis*. Such chromosomes were reported by Darlington (1936) in *Chorthippus* and *Stauroderus*. The terminal chromosomes observed by Darlington (1929) in *Zebrina*, by

Levan (1932) in *Allium* and by Upcott and La Cour (1936) in a triploid garden Tulip *Zomershoon* also resemble those of *Tenagocharis*.

During meiosis seven bivalents are formed (Fig. 6) and the division proceeds with remarkable uniformity (Sundar Rao, 1946). Rarely, however, eight bivalents were observed (Fig. 7). This is obviously due to premiotic non-disjunction as in *Oenothera* (Hedayatullah, 1932). There are three long and four short bivalents and this is in accord with the size relations found at metaphase of mitosis. The number of chiasmata per bivalent is proportional to the length of bivalents—the long ones having a maximum number of five chiasmata and the short ones a minimum of two. In the case of bivalents that are formed by chromosomes with terminal constrictions, the chiasmata in the short arms slip off easily. Lagging and bridge formation were observed at anaphase II (Fig. 8). In the allied genus *Limnocharis*, Dahl (1940) found bridges and fragments, but fragments could not be observed in *Tenagocharis*.

(b) *Hydrocleis nymphoides* (Willd.) Buchenau (= *H. Commersonii* L. C. Rich., and *Limnocharis Humboldtii* L. C. Rich.) ($2n = 12?$ and 16).

The genus *Hydrocleis* is closely related to *Tenagocharis*, but is more restricted in distribution. It comprises three species of which *H. nymphoides* (Willd.) Buchenau is found in tropical South America, while the other two species, namely *H. Martii* Senbert. and *H. parviflora* Senbert., are natives of Brazil.

The diploid chromosome number was found to be 16 (Fig. 9). This does not agree with the report of Suessenguth (1920), who observed $n = 6$ in the same species collected from Europe. That a variation exists in the European and American materials is interesting and if the future investigations prove the correctness of Suessenguth's observations (*loc. cit.*), *Hydrocleis nymphoides* will figure as an interesting example of intraspecific chromosome races with $n = 6$ and 8.

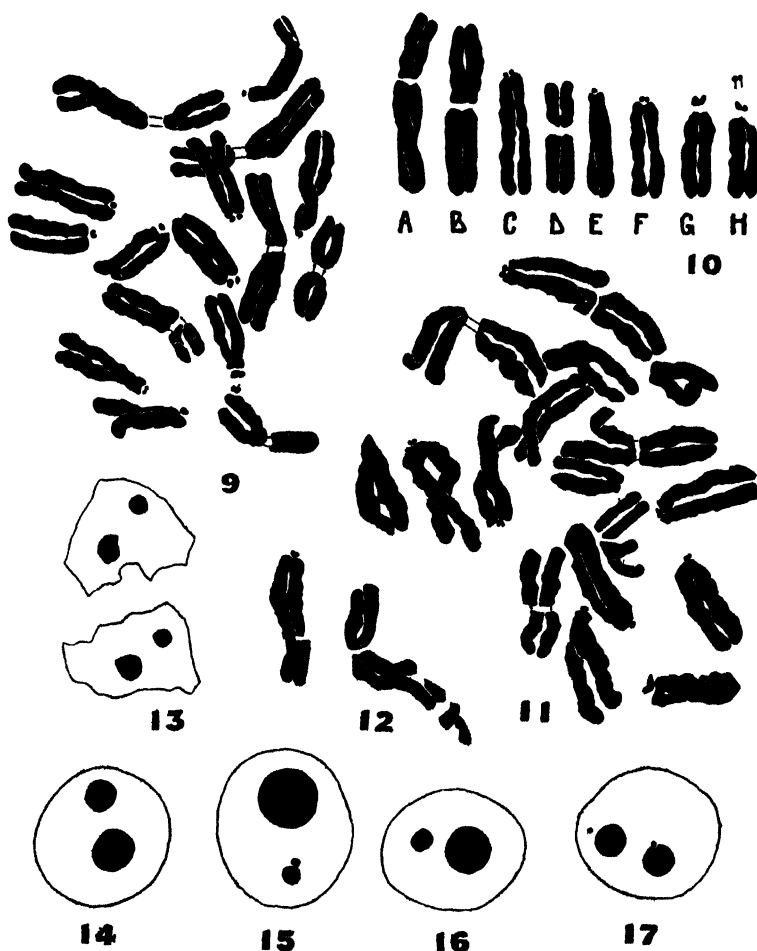
On the basis of the length, the position of attachment constrictions and satellites, the chromosomes of the haploid set (Fig. 10) fall roughly into four types, which are as follows:

- (1) Two long chromosomes of slightly unequal lengths, the first (A) with a distinctly submedian constriction and the second (B) with an almost median constriction;
- (2) four chromosomes, which do not exhibit any marked size variations but show gradation among themselves, all with terminal constrictions (C, E, F and G); the second arms of these chromosomes are extremely small, excepting chromosome (G), which possesses a slightly bigger proximal segment;
- (3) one chromosome (D) with a distinctly submedian constriction, which fits in the graded series of the four preceding ones; it probably comes next to C in length;
- (4) the last chromosome (H), which is probably a little shorter in length than the rest, is terminally constricted and is satellited. The satellite stalks are longer than those of *Tenagocharis*.

Such a chromosome complement shows on the one hand remarkable similarities with that of *Tenagocharis* and on the other dissimilarities that are concomitant on the change in the haploid number from 7 to 8. In fact, the similarity is so striking that the same type of morphologically distinct chromosomes of *Tenagocharis* can be detected in the idiogram of *Hydrocleis*. This undoubtedly indicates a close affinity and common ancestry. The problem will be further discussed in the later part of the paper.

While observing the metaphases in the root-tips treated with colchicine, certain chromosomes showing fragmentation were met with (Fig. 12). It was found that

the chromosomes were more susceptible to breakage at the regions of the attachment constrictions rather than in any other part. Such a breakage at the region of the centromere leads to the numerical increase in the chromosomes associated with the formation of chromosomes having no second arms. For example, Fig. 11 showing 18 chromosomes illustrates the point in question. Karpechenko (1940) observed peculiar transverse division of chromosomes at the region of attachment



FIGS. 9-17. *Hydrocoleis nymphoides*. Fig. 9. Somatic metaphase with 16 chromosomes. Fig. 10. Idiogram. Figs. 11 and 12. To illustrate the phenomenon of fragmentation due possibly to the colchicine action. Fig. 13. Somatic telophase with two nucleoli in each daughter nucleus. Figs. 14-17. Resting nuclei to show two nucleoli of variable sizes and the minute bodies, which are a little away from the nucleoli. \times about 2,466.

constriction in colchicine treated root-tips of barley. This was attributed by him to some changes in the spindle attachment region and was considered by him as a possible secondary effect, arising out of the suppression of the spindle. Eigesti (1940) and Krythe (1941) also recorded fragmentation of chromosomes in their colchicine treated materials.

Other chemicals are also known to bring about the same structural change in the chromosomes. Levan and Tjio (1948*a* and *b*) observed fragmentation of chromosomes due to the action of phenols. Naphthalene (Avanzi, 1950-51) and other chemicals like benzedrine, acenaphthene, 9 aminoacridine, phosphine 5 G (D'Amato, 1950*b*) and Gammexane (D'Amato, 1950*a*) are also known to bring about the same type of structural changes (*cf.* also D'Amato, 1950-51*a*; Tarabusi, 1950-51).

It is now known that spontaneous structural changes are responsible for the variation in the chromosome number within a species as in *Miersia chilensis* (Cave and Bradley, 1943). It is also known, as in *Vicia faba* (D'Amato, 1950-51*b*), that identical chromosome breakages appear spontaneously as well as under the influence of mustard treatments. In *Hydrocleis nymphoides*, however, it could not be determined with certainty whether it is a case of spontaneous fragmentation of chromosomes in certain cells of the somatic tissues, or it is due to the action of colchicine. Material, which was not prefixed in colchicine, was not available for study. But for the present, it is attributed to the action of the drug, as it occurred in the material treated with colchicine of a high concentration (0.25%). In passing it may be remarked here that polyploidisation due to the action of colchicine is sometimes associated with structural changes. The first suggestion of this type was made by Bergner, Avery and Blakeslee (1939). Vaarama (1947) inferred segmental interchanges in colchicine induced autotetraploid *Ribes nigrum*. The sterility of some induced polyploids may perhaps be partly due to such changes.

Figs. 14-17 show size variations of nucleoli in the resting nuclei. A pair of unequal nucleoli is of frequent occurrence and these correspond to the two nucleoli in the telophases (Fig. 13). In favourable preparations stained with crystal violet, two deeply staining bodies of variable sizes were found in close proximity of the two nucleoli but not in intimate association with them. These probably represent the heterochromatic regions of the SAT-chromosomes and the fact that they are a little away from the nucleoli shows that these regions are subterminal in position as pointed out by Bhaduri (1944) in *Scilla*.

(c) *Limnocharis flava* (L.) Buchenau ($2n = 20$).

This genus is distributed not only in tropical America but also in Siam and Java. Between the two varieties, namely *L. flava* var. *minor* Micheli and *L. flava* var. *indica*, Buchenau (1903) found no distinction. Probably, they are local varieties. The material for the present study was obtained from Singapore, Malaya.

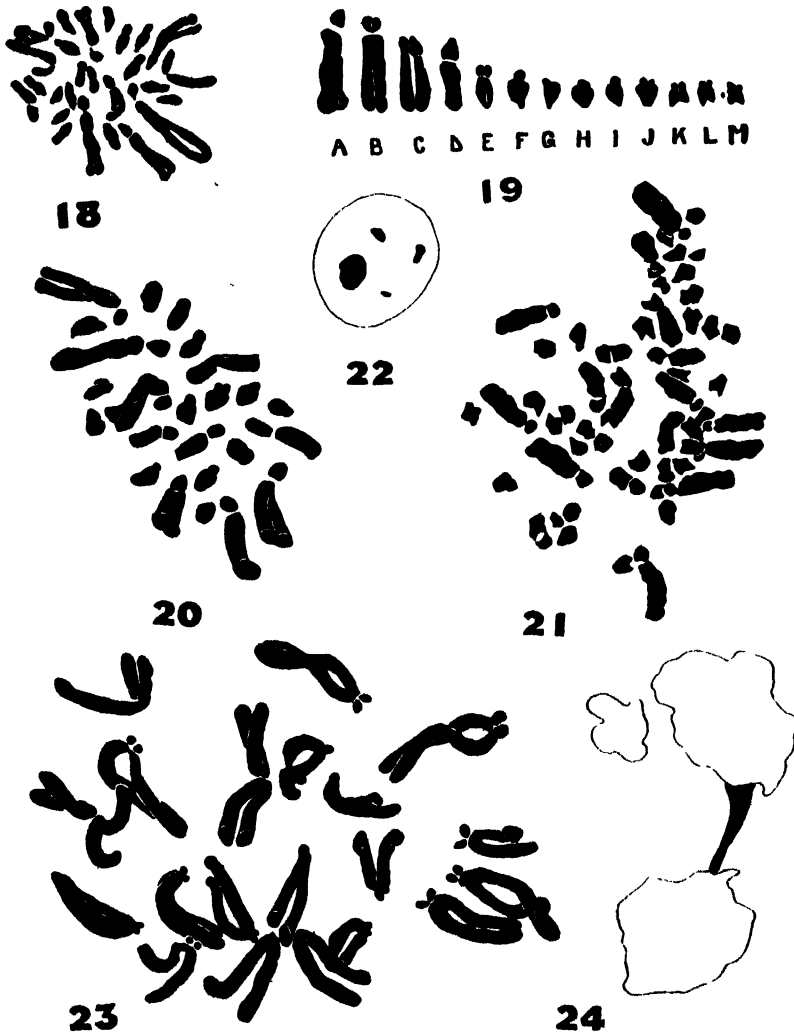
There are 20 chromosomes in the root-tip cells (Fig. 23). Though a critical study could not be made, the following chromosome types were recognised:

- (1) One pair of long median chromosomes, which are quite distinct in the karyotype;
- (2) the rest, which roughly form graded series with no marked variation in the size, all with terminal constrictions.

The length of the proximal arms of these chromosomes varies within a limited range. The present observation of twenty somatic chromosomes is consistent with the observations of Dhal (1940), who worked out the meiosis and the structure of pollen grains.

One of the most interesting features observed during the present study is the occurrence of a somatic bridge without a fragment. A single case was observed and it is shown in Fig. 24. The chromosomes at the two poles, which have apparently lost their identity ('tessement polari'), are connected by a rather stout chromatic bridge, which is thick at one end and thin at the other. It is very likely that the breaking point of this bridge is at the thin region. Jacob (1940) in *Clitoria ternatea* and Pathak (1940) in *Crocus* observed somatic bridges, the former with fragments and the latter without them. Husted (1936) and Riley (1936) recorded such bridges after irradiation. The formation of bridges will result in the unequal

distribution of chromatin material in the daughter nuclei and cause the chromosome unbalance.



FIGS. 18-21. *Butomus umbellatus*. Fig. 18. Somatic metaphase showing 26 chromosomes; note the 4 pairs of distinctly long chromosomes. Fig. 19. Idiogram. Fig. 20. Somatic metaphase with 24 chromosomes. Fig. 21. Somatic metaphase, showing about 50 chromosomes. Fig. 22. A resting nucleus with 4 nucleoli. \times about 3,065.
 „ 23-24. *Limncharis flava*. Fig. 23. Somatic metaphase with 20 chromosomes. Fig. 24. To show somatic bridge. \times about 3,387.

(d) *Butomus umbellatus* L. ($2n = 26, 28, 39$ and 40).

It is distributed in the temperate parts of Europe and Asia in a zone running parallel to that of *Tenagocharis*. A review of the literature shows that this monotypic genus is remarkable for variation in the chromosome number. Liehr (1916) has reported 8 haploid and 16 diploid chromosomes. Holmgren (1913) observed $n = 11-12$ and $2n = 22$ chromosomes. The correctness of the reports by these

two authors must await confirmation by further study of plants collected from different localities. Terby (1922) counted in the root-tip cells $2n = 40$ and this was later confirmed by Lohammar (1931; in Löve and Löve, 1942, 1948; and personal communication) who also reported $2n = 28$ and $2n = 39$. Whitaker (1934) recorded 26 diploid chromosomes for the plants collected from America. If the reports of Liehr and Holmgren are ignored for the present, the chromosome numbers of *Butomus umbellatus* fall under four categories, namely $2n = 26, 28, 39, 40$.

The plants collected from India have 26 somatic chromosomes (Fig. 18). This is in agreement with the reports of Lohammar (1931) from Sweden and Whitaker (1934) from America. In spite of careful search in different plants of variable sizes and from different localities in India, no deviation from the normal number was found during the present investigation. The study of the chromosome morphology has revealed interesting details. Three distinct sizes of chromosomes, namely long, medium and short, are sharply distinguishable and they have the following morphological characters as shown in the idiogram (Fig. 19):

- (1) Three pairs of long chromosomes with subterminal constrictions (A, B and C);
- (2) one pair of long chromosomes with submedian constrictions (D);
- (3) one pair of medium-sized chromosomes with submedian constrictions (E);
- (4) eight pairs of short chromosomes with subterminal or terminal constrictions (F-M).

Cells with deviating chromosome numbers. Among many cells that were observed in the somatic tissues, two cells with 28 and one cell with 24 chromosomes (Fig. 20) were found. The number 26 appears to be the most stable number for the genus from which the other oscillating numbers in different cells must have been derived. Farmer and Shove (1905) in *Tradescantia*, Gates (1912) in *Oenothera*, Belling and Blakeslee (1924) in *Datura*, De Mol (1926) in *Hyacinthus*, Navashin (1930) in *Crepis tectorum*, Mohr (1932) in *Drosophila*, Jacob (1940) in *Clitoria ternatea* and Sikka (1940) in *Brassica Tournefortii* have reported the same feature. This is explicable on the basis of non-disjunction. If some chromosomes fail to separate and pass to the same pole, cells with $2n+2$ and $2n-2$ will arise as in *Butomus*. Sometimes non-division, non-congression and fragmentation may also lead to the formation of cells with hyper- and hypoploid nuclei. The occurrence of such cells in *Butomus* is significant, as races with 28 chromosomes have been reported by Lohammar (1931).

One cell with about 50 chromosomes (Fig. 21) was also observed during the present investigation. This is a case of somatic doubling.

V. DISCUSSION.

(a) Evolutionary tendencies in the family.

As long ago as 1903, Buchenau presented a monographic treatment of the family, but he paid little attention to the phylogenetic relationships and the evolutionary tendencies among the several genera. Many years later, Salisbury (1926) reviewed the then existing knowledge on the floral morphology of the Helobiales, including certain members of the family Butomaceae and formulated the general lines along which the group as a whole tends to show variation in the floral constitution. According to him: the extraordinary uniformity in the androecial structure in Helobiales indicates that the six antisepalous stamens of the various members of the group are homologous and that their paired nature is due to the congenital fission, which is a group tendency. One of those important lines, which has a particular bearing on Butomaceae, is the staminal fission normally seen in

certain members as a congenital dedoublement of the outermost whorl. In other words, the presence of 6 or fewer stamens is an ancient character and the androecium with numerous stamens is derived from it. Another tendency, which was not mentioned by Salisbury (*loc. cit.*), is the gradual increase in the number of carpels, going hand in hand with the staminal dedoublement. On the basis of this and other tacit assumptions of Salisbury, it may be possible to visualise a whole ascending series exhibiting a gradual increase in the complexity of floral organisation within Butomaceae. *Tenagocharis latifolia* with 9 fertile stamens stands at the lowest level and *Limnocharis flava* with numerous stamens is the highest evolved in the family. The latter shows the extreme development of this fission tendency and has therefore come to possess numerous whorls of stamens, of which the outer ones are sterile. If both androecial and carpellary conditions are taken into consideration, *Hydrocleis nymphoides* with few carpels and numerous stamens occupies probably an intermediate position between the two extremes shown by *Tenagocharis* and *Limnocharis*. The question of *Butomus* from this point of view will be discussed later on.

There may not be universal agreement among the morphologists regarding the validity of the hypothesis proposed by Salisbury for the group Helobiales in general and its applicability to Butomaceae in particular (*cf.* Buchenau, 1903; Rendle, 1930). Nevertheless, with the available cytological knowledge, it can form a valuable basis for understanding the mode of evolution in the family particularly when considered with a special reference to (i) the chromosome numbers and (ii) karyotype evolution.

(i) *Chromosome numbers*:—Cytologically the three genera, *Tenagocharis*, *Hydrocleis* and *Limnocharis*, all of which are characterised by long chromosomes, form a highly homogeneous group with basic numbers 7, 8 and 10 (excluding for the present $n = 6$ reported by Suessenguth, 1926, for *Hydrocleis*). Hence, the intergeneric relationships in the family are determined by aneuploidy (*cf.* Cruciferae, Manton, 1936; Commelinaceae, Geitler, 1939; Leguminosae, Senn, 1938). Polyploidy has played but little part in connection with the origin of the genera. From a comparison of all the chromosome numbers in the family, it is likely that *Butomus umbellatus* ($n = 13$) is an amphidiploid, which originated from putative parents with 6 and 7 haploid chromosomes. At least some such ancestors are not far to seek in the family. The alternate hypothesis that it is a tetraploid based on 7 series with a subsequent loss of two chromosomes would be round about and it would be difficult to imagine the establishment of such a tetraploid, which suffered a loss of certain chromosomes. Furthermore, a critical appraisal of the divergent features of its karyotype when compared with those of the related genera immediately disproves the autotetraploid origin of *Butomus*. Aneuploid mode of origin also is not tenable as this genus does not fall under the scheme of fragmentation, discussed in this paper in connection with the origin of genera.

Amphidiploidy as a factor in evolution of categories higher than species has been recognised in a number of cases of flowering plants (Anderson, 1937*a* and *b*). The basic chromosome number 19 encountered in Magnoliaceae (Whitaker, 1933), *Populus* (Blackburn, 1929; Wettstein, 1933) and *Salix* (Sinoto, 1929; Nakajima, 1937), the number 41 in *Tilia* (Dermen, 1932) and 23 in *Fraxinus* (Sax and Abbe, 1932) are of polyploid origin. There is considerable evidence to show that Pomoideae, the whole subfamily of Rosaceae might have had amphidiploid origin (Sax, 1931; Darlington and Moffet, 1930). The same is the case with the subfamily Oleoideae of Oleaceae, which is characterised by a uniform and stable chromosome number $n = 23$ (Taylor, 1943). Anderson (1934) went even a step further to suggest that angiosperms or at least some of the families might have originated in some such fashion. In the family Butomaceae amphidiploidy appears to be a method of evolutionary divergence resulting in the origin of a unique genus like *Butomus*.

An examination of Table I reveals that the lowest and the most frequent chromosome number of *Butomus umbellatus* is $2n = 26$ and that aneuploids and triploids with $2n = 28$ and $2n = 39$ chromosomes respectively exist in the species (Lohammar, personal communication). The former might have originated due to chromosome duplication on account of some irregularities in meiosis and the latter due to the fusion of a haploid and a diploid gamete. In both the cases no marked change in the phenotypic characters can be expected and the inherent vegetative propagation makes possible the survival of such races in nature, particularly the triploids. Much more interesting, however, is the occurrence of plants with $2n = 40$ chromosomes (Terby, 1922). A triploid mode of origin of such a race from plants with 26 and 28 somatic chromosomes is most probable. If a diploid gamete of the former fuses with the haploid gamete of the latter, a triploid with 40 chromosomes is formed ($2n = 26 + 14 = 40$). Terby's figures show that all the chromosome types are found in triplicate. Its origin can also be explained from the normal 26 chromosomal forms on the assumption that unreduced gametes may sometimes contain more than the somatic chromosome number owing to the meiotic irregularities. Thus a *Butomus* with $2n = 26$ might very well form unreduced ovules with 27 chromosomes. If fertilisation takes place with normal pollen having 13 chromosomes, a race with 40 chromosomes is formed.

Löve (1951) claims that the triploid races of Scania can be morphologically distinguishable on account of their sterility and their higher degree of bulbiliferity. In respect of the latter character, triploid races are like hexaploid *Allium Babingtonii* and *A. roseum* var. *bulbiliferum*, which reproduce in nature by bulbils (Maude, 1940). When compared with all the related genera, *Butomus* has a wide range of geographic distribution, presumably on account of its autopolyploidy and its capacity for vegetative propagation.

(ii) *Karyotype evolution*:—*Tenagocharis*, *Hydrocleis* and *Limnocharis* show a remarkable resemblance in having morphologically similar chromosomes in their karyotypes. Hence, the various chromosome types are of great taxonomic value. *Tenagocharis* ($2n = 14$) with four pairs of median or submedian and three pairs of terminal chromosomes, *Hydrocleis* ($2n = 16$) with three median or submedian and five pairs of terminal chromosomes and *Limnocharis* with only one pair of median chromosomes and the rest with terminal constrictions form a progressive aneuploid series in the family.

On the basis of the hypothesis of Lewitsky (1931) and Levan (1935), that the primitive types have median or submedian constrictions, while with advancing evolution the chromosomes become subterminally constricted, the karyotype of *Tenagocharis* should represent the most primitive type in the family. Relatively, the karyotypes of *Hydrocleis* and *Limnocharis* are more asymmetrical (cf. related genera of Crepidinae, Babcock, Stebbins and Jenkins, 1937). The progressive increase in the asymmetry of the karyotypes and the successive increase in the base numbers of the genera due to the sudden replacement of a median or submedian chromosome by two terminally constricted chromosomes is explicable by assuming fragmentation during the course of phylogeny. Anderson (1931) envisaged a similar mode of origin for *Nothoscordum bivalve* ($n = 9$) with two terminally constricted chromosomes from an eight chromosomal stock by the division of a large medianly constricted chromosome. This fact was later corroborated by Beal (1932), who discussed the origin of *Nothoscordum* from *Allium*. Levan (1932) has given an extensive survey of the part played by fragmentation in phylogeny.

The evolutionary significance of fragmentation in the origin of species and genera has been a matter of much controversy. The apparent difficulty underlying such a concept is the origin of a new centromere in the acentric fragment, so that it can function readily as a normal chromosome both in meiosis and mitosis. However, in the light of many publications, such as Delaunay (1926), Darlington

(1929), Mather (1932), Levan (1935), Sato (1937), Beal (1939), Cave and Bradley (1943), Bhaduri and Bose (1947), Wilkinson (1944) and Müntzing (1945), it is now increasingly evident that fragmentation has played an important part in the phylogeny of the genera. Moreover, the work of Tjio and Levan (1950) and Lima-de-Faria (1950) on the structure of the centromere, the work of Upcott (1937) in *Tulipa*, where the chromosomes undergo fragmentation at II division, the products of division surviving with terminal centromeres and the more recent work of Darlington and La Cour (1950) showing that the divided halves of a chromosome need not always form isochromosomes but remain functional as two terminally constricted chromosomes and the work of Sears (1952) on the origin and behaviour of telocentric chromosomes in wheat bring out the importance of fragmentation as an evolutionary process.

Furthermore, the sporadic occurrence of plants with terminally constricted chromosomes in natural populations of certain genera goes to prove that fragmentation is at work in nature. For example, Garber (1944) recorded spontaneous alteration in both chromosome number and morphology in fairly fertile *Nothoscordum fragrans*, collected from Charleston, S. Carolina (U.S.A.). One of the outstanding features of anaphases I was the presence or the absence of whole chromosome arms but nevertheless having sister complements which are equal both in number and morphology. It is equally remarkable to note that in none of the anaphases I, chromosome arms as acentric fragments were observed by him. Garber (*loc. cit.*) attributed this type of variance to fragmentation at the region of or adjacent to the centromere in the cells of the sporogenous tissue prior to meiosis and to the genetic inertness of whole arms of chromosomes.

Levan and Emsweller (1938) have explained the origin of the two terminally constricted chromosomes in a 19 chromosomal *Nothoscordum fragrans* by assuming fragmentation of a medianly constricted chromosome (see also D'Amato, 1949a and b). They also showed that these terminal chromosomes are at least partially homologous with a medianly constricted chromosome on account of their formation of a heterotrivalent.

In a triploid population of *Trillium Hagae*, Matsuura (1950) discovered a unique plant in which one chromosome (type A) was divided into two functional arms, while the other two homologous chromosomes of the same type were normal. He thought that their origin might not imply misdivision at the centromere and called it 'dislocation'.

It is, therefore, abundantly clear that plants with terminal chromosomes sometimes do occur in natural populations and it looks as though that certain species are genotypically predisposed for the development of the terminal chromosomes by fragmentation. If such plants are selected in nature, the initial isolation and therefore independent variation and the ultimate differentiation will lead to the development of new genera and species. Probably, some such mechanism will explain the origin of genera in Butomaceae.

Whatever may be the mechanism which brought about the asymmetry of the karyotypes, cytological changes of major evolutionary importance in Butomaceae consist in the relative disposition of the chromatin material by structural changes. These when added on to the genic changes associated with parallel divergence in the morphological features culminated in the origin of genera like *Hydrocleis* and *Limnocharis* from *Tenagocharis*-like ancestors. A parallel instance is provided by Commelinaceae (Anderson and Sax, 1936). In *Tradescantia* all the chromosomes have approximately median constrictions; in *Rhoeo*, two chromosomes have developed subterminal constrictions; in *Spironema* and *Callisia* four chromosomes have done so. Differentiation of genera in Conifers (Sax and Sax, 1933) and in Amaryllidaceae (Sato, 1938) is also associated with similar structural changes.

(b) *Correlation between chromosome size and the geographic distribution of the genera.*

In the foregoing account it was mentioned that *Butomus* when compared with the other genera is characterised by relatively small chromosomes. It is also clear from its probable origin by amphidiploidy that it is comparatively an advanced genus in the family. Therefore a phylogenetic reduction in the absolute size of all the chromosomes is one of the important trends in the evolution of the family. A tendency towards phylogenetic decrease in the size of the chromosomes was first observed by Delaunay (1926) working with the liliaceous genus *Muscari*. Since then, it has been found operating in the evolution of several genera. The most notable examples are *Crepis* (Babcock and Cameron, 1934) and the group Crepidinae (Babcock, Stebbins and Jenkins, 1937) of Compositae and the genus *Dianthus* of Caryophyllaceae (Rohweder, 1934). Juncaginaceae and Cyperaceae, which are now considered to be derived from Liliaceae, are characterised by smaller chromosomes than the latter (Stebbins, 1950).

Much more significant is the correlation between the size of the chromosomes of the different genera in Butomaceae and their geographic distribution. While *Tenagocharis*, *Hydrocleis* and *Limnocharis* with large chromosomes are confined to the tropical regions with sometimes localised and discontinuous distribution, *Butomus* with small chromosomes has invaded the subtropical and temperate regions of Asia and Europe. In this respect, Butomaceae provides an extremely interesting case because in almost all the previously recorded cases it was found that, in a progressively cooler climate, plants with larger chromosomes were found better adapted than those with smaller chromosomes (cf. Avdulov, 1931 in certain tribes of Gramineae). In the predominantly tropical family Rubiaceae, the highly specialised genus *Galium* with large chromosomes is temperate in distribution (Fagerlind, 1937). The same is the case with the temperate species of *Tradescantia*, which is conspicuous in Commelinaceae in having larger chromosomes than most of its tropical relatives (Darlington, 1929).

(c) *The systematic position of Butomus in the family.*

Karyotypically and morphologically, *Butomus umbellatus* is distinct and different from the other allied genera of the family. Apart from the amphidiploidy ($n = 13$) and the general decrease in the size of the chromosomes, none of the long median chromosomes so characteristic of *Tenagocharis*, *Hydrocleis* and *Limnocharis* are present in the karyotype of *Butomus*. Moreover, there is a reduction in the number of medium-sized chromosomes to one pair and an increase in the number of the short chromosomes.

Associated with these cytological differences are certain specialised morphological features like the presence of a rhizome, the absence of latex, the normal monosporic type of embryo-sac as against the bisporic type of the other genera. Maheshwari (1948) calls attention to the fact that in pollen morphology also *Butomus* does not agree with the rest of the family. According to him, the pollen grains bear a far greater resemblance to Liliales than to any other member of Butomaceae. Thus when the totality of evidence is brought into focus, *Butomus umbellatus* appears to stand apart from the other members of the family, justifying its segregation to an isolated position. In order to explain the origin of three species of *Crepis* with $n = 7$, having entirely different morphological features, Babcock (1947) postulated a hypothesis involving intergeneric hybridisation (cf. also Gates, 1925). It may not be therefore unreasonable that in the origin of *Butomus*, two genera with 6 and 7 haploid chromosomes have taken part, as Anderson (1937b, p. 226) remarks, 'If the parental stocks are distinct enough there is no reason why a new genus or a new family or a new order might not originate in this manner' (i.e. by amphidiploidy).

It has been pointed out earlier, that staminal dedoublement is a progressive phylogenetic tendency in the family and that it finds a cytological correlation with the progressive increase in asymmetry of the karyotypes. *Tenagocharis*, *Hydrocleis* and *Limnocharis* fully agree with this line of evolution. *Butomus*, however, as it possesses 9 stamens and 6 carpels, seems to have remained at a phylogenetically low level of floral organisation like *Tenagocharis*. In this connection, the three related families of Magnoliales, Magnoliaceae, Trochodendraceae and Cercidiphyllaceae having $n = 19$ provide parallel instances. Assuming their chromosome number to be amphidiploid in origin, Gates (1951) remarks that their flower type is primitive in Angiosperms, while the chromosome number is 'advanced'. Hence, phylogenetically important morphological characters on the one hand and the genetic system on the other may be at two different levels of organisation and do not always advance together. It is just possible that *Butomus* diverged from the general pattern of evolution very early in the history of the family on account of amphidiploidy retaining at the same time some of the primitive morphological features.

Taxonomic considerations in Butomaceae and Alismataceae on the basis of the morphological characters of the gynoecium and also on anatomical distinctions have recently led Pichon (1946) to propose a re-alignment of the different genera in the two families and a re-definition of the family Butomaceae. He has suggested that all the genera of Butomaceae, except *Butomus*, might as well be transferred to Alismataceae. Whether this regrouping finds a cytological corroboration or not, the point of immediate interest is that Pichon (*loc. cit.*) also recognised the unique position of *Butomus* in the family and separated it from the rest of the genera.

(d) *Taxonomy of the family in relation to cytology and geographic distribution.*

It is now realised that cytology gives useful information in understanding the taxonomic and evolutionary patterns within a family or a genus. However, as pointed out by Anderson (1937a), the taxonomic usefulness of the information about the chromosome numbers and the purposes to which the information can be put will depend upon the stability in the particular group, which is being studied. Butomaceae is a family of great karyological variability. Morphological, cytological and distributional data can be integrated and brought to bear on the problem of the taxonomy of the family with the result that all the genera fall into two natural groups, which may be given the status of sub-families. It is a matter of considerable interest to note that such a grouping in main is based on the size of the chromosomes and to some extent on the chromosome-types and the basic numbers of the genera. The following are the two groups:

Group 1.—It consists of *Tenagocharis*, *Hydrocleis* and *Limnocharis*, which are characterised by long chromosomes with the basic numbers 7, 8 and 10 and are found distributed in the tropical regions.

Group 2.—It consists of *Butomus* with 13 small haploid chromosomes. It is distributed in sub-tropical and temperate regions.

Such a grouping of the genera based on cytology is in accordance with Buchenau's classification (1903) of the family. The following is the key to the genera as given in *Pflanzenreich* along with the cytological data. The genus *Ostenia* (found in Uruguay), included in the family by Hutchinson (1934) and Rendle (1930), was not given any place in the scheme of classification by Buchenau and hence is omitted here for the present.

- A. Embryo erect, stamens 9, all fertile, with
no latex, $n = 13$, chromosomes small,
temperate middle Europe and Asia .. 1. *Butomus* L.

- B. Embryo curved, plants with latex, chromosomes *Tenagocharis*-like, large, median, submedian and terminal.
- (a) Stamens 9, all fertile, $n = 7$, tropical Africa, India and N. Australia 2. *Tenagocharis* Hochst.
- (b) Stamens numerous, external sterile.
- (i) Carpels ∞ , vertical, apical, sessile stigma extrorse, $n = 10$, large *Tenagocharis*-like chromosomes, tropical S. America, Siam and Java 3. *Limnocharis* Humb. et Boupl.
- (ii) Carpels 6, sensim in stylum longum et stigma papillosum, introrse attenuata, $n = 8$, large chromosomes, tropical S. America (Brazil) .. 4. *Hydrocleis* L. C. Rich.

There are a few other instances in the literature which illustrate the value of cytological data in the classification of the family as in Butomaceae. Avdulov (1931) divided the family Gramineae into three karyo-systematic groups, distributed in two sub-families. The first group forming the sub-family Saccariferac (Harz) Avdulov has the basic numbers 9 and 10 and is characterised by small chromosomes; the geographic distribution is tropical or sub-tropical. The second group Festucaeformes Avdulov is known by 7 or a lower basic number and long chromosomes and is confined in main to the temperate and polar regions. The third group Fragmitiformes (Harz) Avdulov with small chromosomes and a basic number 12 is found distributed in an essentially tropical belt. The second and the third groups together form the second sub-family, Poatae (Hitchcock) Avdulov. In the family Ranunculaceae, Gregory (1941) recognised the existence of two groups of genera, one with long *Ranunculus*-type and the other with small *Thalictrum*-type of chromosomes, both of which are characterised by a parallel fruit development.

The family Diapensiaceae is classified in the same manner into the Tribe Diapensiaceae with 5 genera ($2n = 12$) and the Tribe Galacineae with only one genus ($2n = 24$) (Baldwin, 1939). Taylor (1945) recognised in Oleaceae two sub-families, namely Oleoideae ($n = 23$) and Jasminoideae ($n = 11, 12, 13$ and 14), the former with allopolyploid origin from the latter. Magnoliales show a tendency to split themselves into two groups, a 14 and a 19 chromosome series. Hutchinson (1924) classified the group into five families with these two groups of genera scattered among them. Additional morphological data which have been scarcely used may eventually support the relations indicated by cytology (Whitaker, 1933).

VI. SUMMARY.

(1) A cytological investigation has been undertaken into the chromosome constitution of four genera of Butomaceae, namely *Tenagocharis*, *Hydrocleis*, *Limnocharis* and *Butomus*, in order to understand their phylogenetic and taxonomic relationships.

(2) *Tenagocharis latifolia* ($n = 7$), *Hydrocleis nymphoides* ($n = 8$) and *Limnocharis flava* ($n = 10$) form progressive aneuploid series with a gradual increase in the asymmetry of the karyotypes. Judging their phylogenetic status from this point of view, *Tenagocharis* with few stamens and carpels is most primitive and *Limnocharis* with numerous stamens and carpels is the highest evolved in the family. *Hydrocleis* probably is intermediate between these two extremes.

(3) Fragmentation of the chromosomes appears to have played an important part in the evolution of these genera.

(4) On the basis of the comparative study of the chromosome numbers, the genus *Butomus* ($n = 13$) appears to have had an amphidiploid origin from putative parents with 6 and 7 haploid chromosomes. Standing apart from the other genera on account of the possible amphidiploidy, *Butomus* remained at about the same phylogenetic level as *Tenagocharis* from a morphological point of view. It looks as though chromosome organisation and morphological pattern can be at two different levels.

(5) If the chromosome size is correlated with the geographic distribution of the genera, it is remarkable to find that the genera like *Tenagocharis*, *Hydrocleis* and *Linnocharis* with large chromosomes are tropical while *Butomus* with small chromosomes is sub-tropical and temperate.

(6) Buchenau's classification (1903) of all the genera into two groups is confirmed by the present cytological study.

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TARGET PENETRATION BY HIGH-VELOCITY 'MUNROE' JETS

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1. INTRODUCTION.

An article by Birkhoff *et al.* (1948) presented hydrodynamic theories of jet formation and target penetration by explosives with lined conical cavities. The theory of jet formation did not explain satisfactorily the velocity gradient, 'after-jet' effect and the dependence of penetration on the 'standoff'. The authors have concluded that, to a first approximation, the depth of penetration by a jet into a given target is independent of the velocity of the jet and depends only upon its length and density. Assuming the velocity gradient along the jet, which is responsible for its lengthening and the change of its effective density as it travels, they have also discussed, in a qualitative manner, the effect of 'standoff' on the penetration. They have not taken into consideration the elongation of different elements of a jet when it is penetrating a target and the strength of the target. Recently Pugh *et al.* (1952), by assuming a variable instead of a constant collapse-velocity for the walls of the conical liner, have explained the formation of the entire jet (including the 'after-jet') and the velocity gradient. Pack and Evans (1951) have divided the action of the jet into two stages, primary and secondary penetration. Primary penetration takes the strength of the target into account.

The exact physical state of metal in a Munroe jet is not yet known. The gradient in velocity along the jet causes it to lengthen as it travels and to change its physical characteristics, which are undoubtedly very complex. To evaluate the effective density of the jet at any time, as it travels, it has been necessary to make some simplifying assumptions. The object of the theoretical work described here is to correlate the mechanism of jet formation with the primary penetration at different 'standoffs' (say below 4 times the calibre), taking into consideration the elongation of each element of the jet as it travels in space, the elongation which occurs as it penetrates the target and the strength of the target. The kinetic energy of the jet, increment in volume of the hole as it penetrates a target and its momentum have also been discussed.

2. DEPTH OF PENETRATION.

According to Birkhoff *et al.*, when a high-velocity jet impinges upon a target, it produces pressures close to a quarter million atmospheres, which force the target material to flow plastically out of the path of the jet. Evans and Ubbelohde (1950) have shown that there is a negligible loss of the target material due to the hole formation by a Munroe jet and the displacement of the target material is normal to the axis of the hole.

Let us consider a variable jet* and imagine it to be divided into small elements, each having a definite velocity. Eichelberger and Pugh (1952) have discussed that

* By a 'variable jet' we mean a jet along which velocity gradient exists.

the velocities of the jet elements remain constant during their travel (at any rate for small 'standoffs') and adjacent elements do not affect each other appreciably during penetration. At any particular instant, during penetration, the element at the head of the jet is knocked off, making passage for the subsequent elements to pass through practically undisturbed and the process repeats. Each successive element of the jet has to travel a little more than the preceding one by the distance which the previous element has penetrated. Thus the elongation of the jet goes on even while the jet is penetrating the target.

Let us take a small element dL of the jet (having V_j as the velocity of the head of the element and V_j' the velocity of its tail) that is about to strike the target at a given instant of time. It is assumed that the small element dL of the jet obeys the steady state conditions (as discussed by Birkhoff *et al.*). For the particular element under consideration, let V represent the mean velocity $(V_j + V_j')/2$, $\lambda\rho_j$ the effective density and U the rate of increase of the length of the hole. Let ρ_T be the density of the target. Assuming the strength of the target to be negligible, the pressure exerted by the element of the jet is $\frac{1}{2}\lambda\rho_j(V-U)^2$ and that by the target is $\frac{1}{2}\rho_T U^2$. Equating the pressure in the element of the jet to that in the target at the stagnation point, we have

$$\lambda\rho_j(V-U)^2 = \rho_T U^2 \quad \dots \quad (1)$$

The time during which pressure is exerted on the bottom of the hole is $dL/(V-U)$. The depth of penetration dP is given by

$$dP = \frac{dL}{V-U} U = dL \sqrt{\frac{\lambda\rho_j}{\rho_T}} \quad \dots \quad (2)$$

Pack and Evans (1951) have suggested that the penetration is reduced by a factor $(1-kR)$ when the target strength is taken into consideration, where R is proportional to the initial yield stress of the target material and k depends on the properties of the jet and the density of the target. When the velocity gradient is taken into consideration, it is justified to assume Pack and Evans' modification to hold for the small element dL of the jet under consideration. The primary penetration dP by that element is given by the expression

$$dP = dL \sqrt{\frac{\lambda\rho_j}{\rho_T}} (1-kR) \quad \dots \quad (3)$$

The present work aims at devising a method of evaluating the total penetration by the jet. The evaluation of k , dL , $\lambda\rho_j$ and dP are discussed in the following sections.

3. EVALUATION OF k

Evans and Pack (1951) have suggested that for dynamic penetration by a jet (after it has penetrated the first few cms.), the following relation holds good

$$\text{Work done by a jet to make a hole} = R \times \text{Volume of hole} \quad \dots \quad (4)$$

R for materials which do not harden appreciably is of the order of 3.5 to 4 times the initial yield stress and for annealed metals between 5 to 6 times the yield stress (Bishop, Hill and Mott, 1945).

The correction for the strength of a target is made by adding R to the pressure in the target and equating that to the pressure in the jet at the stagnation point, we have

$$\lambda\rho_j(V-U)^2 = \rho_T U^2 + 2R \quad \dots \quad (5)$$

or

$$\frac{U}{V-U} = \sqrt{\frac{\lambda \rho_j}{\rho_T}} \left\{ 1 - 2 \frac{R}{\lambda \rho_j (V-U)^2} \right\}^{\frac{1}{2}}$$

as a first approximation

$$\begin{aligned} \frac{U}{V-U} &= \sqrt{\frac{\lambda \rho_j}{\rho_T}} \left\{ 1 - \frac{R}{\lambda \rho_j (V-U)^2} \right\} \\ &= \sqrt{\frac{\lambda \rho_j}{\rho_T}} \left\{ 1 - \left(\frac{1}{V \sqrt{\lambda \rho_j}} + \frac{1}{V \sqrt{\rho_T}} \right)^2 R \right\} \end{aligned}$$

The depth of primary penetration dP is then given by

$$dP = \frac{dL}{V-U} U = dL \sqrt{\frac{\lambda \rho_j}{\rho_T}} \left\{ 1 - \left(\frac{1}{V \sqrt{\lambda \rho_j}} + \frac{1}{V \sqrt{\rho_T}} \right)^2 R \right\} \dots \dots (6)$$

writing

$$k = \left(\frac{1}{V \sqrt{\lambda \rho_j}} + \frac{1}{V \sqrt{\rho_T}} \right)^2 \dots \dots \dots (7)$$

the eq. (6) reduces to

$$dP = dL \sqrt{\frac{\lambda \rho_j}{\rho_T}} (1 - kR) \dots \dots \dots (3)$$

which is the same as eq. (3). kR is a non-dimensional parameter.

To have an idea of the magnitude of the target strength-correction-factor, let an element at the head of a jet have a mean velocity 7×10^5 cm./sec., effective density $\lambda \rho_j$ 7.8 gm./c.c.; while another element at the tail end of the jet have a mean velocity 2×10^5 cm./sec. and effective density $\lambda \rho_j$ 5 gm./c.c. The dynamic yield stress is taken as proportional to the static yield stress and the value taken is 3.3×10^9 dynes/cm.² R is taken as 6 times the yield stress. Then for a target of density 7.8 gm./c.c. the target strength-correction-factor $(1 - kR)$ comes out to be 0.98 and 0.68 for the head and the tail end of the jet respectively. Hence for a given target, when the head of a jet is penetrating, the primary penetration depends only on the jet characteristics; on the other hand, when the tail end is penetrating, the primary penetration depends on the jet characteristics and the target strength.

4. LENGTH OF THE JET.

In a recent paper, the author (1953) has given an explicit expression for the length of a jet. When a detonation wave sweeps from the apex to the base along a conical liner AMB (Fig. 1), the element M collapses and moves towards the axis with the velocity V_0 along a line that makes an angle A with the perpendicular to the axis AQE . On reaching the axis of the liner at Q (at instant t), the element divides into two elements dm_s and dm_j , which proceed along the axis at the constant velocities V_s and V_j respectively. The position of M in the parent conical liner is fixed by a length x measured from the apex along the axis to the plane of the zonal element M and that of Q by a length Y measured from the apex along the axis. Let Y' , V_j' , t' , etc. refer to the corresponding parameters for the element M' . When a finite element MM' is considered, at the instant t' , it is completely changed into a slug and a jet. Let ΔL be the length of this element of jet having

V_j as the velocity of the head of the element and V'_j the velocity of its tail; then ΔL is given by

$$\Delta L = V_j(t' - t) + Y - Y' \quad \dots \quad (8)$$

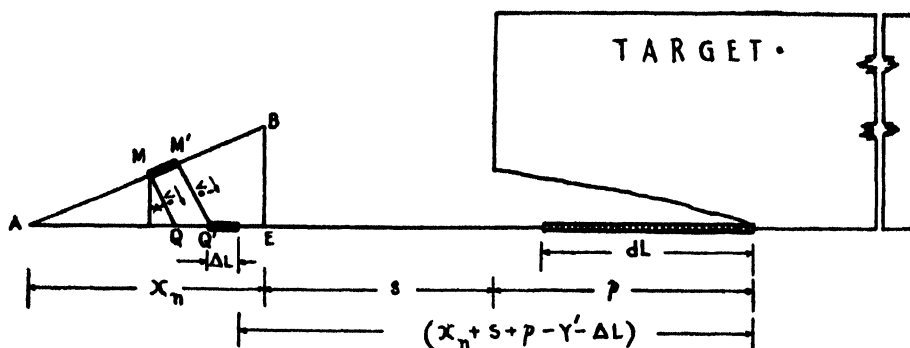


FIG. 1. AMB is the upper half and AQE is the axis of the original conical liner. ΔL represents the length of the jet arising from the finite element MM' at the instant t' . ΔL elongates to dL when it is about to strike the target. p represents the penetration by the jet arising from AM length of the original liner. (The thicknesses of the element MM' and that of the jets ΔL and dL are shown in the figure.)

Let there be a massive target at a 'standoff' S and let us suppose that the jet arising from the length AM of the original conical liner has already penetrated a distance p in the target. The element of jet ΔL (arising from MM') elongates due to the velocity gradient and attains the length dL just before striking the target, where

$$dL = \Delta L + \frac{x_n + S + p - Y' - \Delta L}{V_j} (V_j - V'_j) \quad \dots \quad (9)$$

x_n being the total height of the conical liner. ΔL and dL can be evaluated provided the exact mechanism of collapse (i.e. the curves of V_j , V_0 and β as functions of x) of the liner is known. Eichelberger and Pugh (1952) have published such curves for one particular liner.

5. EFFECTIVE DENSITY OF THE JET.

As pointed out by Birkhoff *et al.* there are two types of jets—'Fluid' and 'Fragment'. λ equals one for a fluid jet and two for a fragment jet. If a jet is intermediate between these two types, λ takes values between one and two. They have also discussed the change of effective density for a variable jet as it travels.

Pugh *et al.* (1951) have obtained the visible light photographs of jets. The front end of the jet is incandescent and vaporised. The remainder of the jet is relatively non-luminous. The tip of the jet appears to consist of a large number of high speed particles travelling nearly parallel to the jet. These particles vaporise continuously by their rapid passage through air.

As the exact physical state of the metal under the conditions of temperature and pressure prevalent in the jet is not known, some plausible assumptions have been made in the discussions of the problem. Three cases have been considered here, all of which may occur at different stages in the same jet.

Case 1.—Let ρ represent the density of the metal in the original conical liner. The relatively small compressibility of the metal in the liner is neglected and it is assumed that when a small element MM' in the original liner changes into the jet

of length ΔL (at the instant t'), the density of the jet element $\rho_{j,0}$ is the same as that of the metal in the original liner.

The element ΔL of the jet that is just formed starts to move along the axis of the equipment having V_j the velocity of its head and V'_j the velocity of its tail. The jet is drawn out like a ductile metal and becomes narrower. It acts as a fluid jet and the jet density $\rho_{j,0}$ (which is equivalent to ρ) is constant. λ is a constant and equals one for a fluid jet. Hence eq. (3) may be written as

$$dP = dL \sqrt{\frac{\rho}{\rho_T}} (1 - kR) \dots \dots \dots (10a)$$

Case 2.—The ductile drawing cannot go on indefinitely. It is assumed that the ductile drawing in case of a jet goes on till the length dL equals $C\Delta L$ (C is a constant) and further lengthening of the jet causes it to break up into particles. Once a jet breaks up into fragments, it is assumed that as the jet travels, its cross-section remains constant (at any rate for small 'standoffs'). Then the conservation of mass equation gives

$$\pi r_j^2 \rho C \Delta L = \pi r_j^2 \lambda \rho_j dL$$

where r_j is the radius of the jet. From the above equation

$$\lambda \rho_j = \rho C \Delta L / dL \dots \dots \dots (11)$$

Substituting the value of $\lambda \rho_j$ in eq. (3), we get

$$dP = \sqrt{\rho C \Delta L} dL / \rho_T (1 - kR) \dots \dots \dots (10b)$$

Thus the primary penetration dP is given by the eq. (10a) or (10b) depending whether $dL <$ or $> C\Delta L$ respectively.

From the best overall fit of the experimental and the theoretical 'penetration-standoff' curves, a suitable value of C can be chosen. For a steel jet, it is suggested that, when dL equals $1.5\Delta L$, the ductile drawing or the plastic expansion ends and the jet starts breaking into particles. This value is comparable to that given by Mott (1947) for plastic expansion of cylindrical shell cases, composed of a ductile material such as steel. The ductile drawing for an aluminium or cadmium jet may be more than the one assumed above for the steel jets.

Case 3.—The above calculations will be applicable up to optimum 'standoff', i.e. up to the point beyond which the experimental curve of penetration against 'standoff' decreases. To explain the decrease of penetration beyond optimum 'standoff' some other assumption will have to be made. Birkhoff *et al.* have discussed such a case by considering the lengthening of a jet and by assuming that there is a radial spread which is linear with 'standoff' and symmetrical along the axis.

6. CALCULATIONS OF THE PENETRATION BY VARIABLE JETS AT SMALL 'STANDOFFS'.

In this section, the method of calculating the penetration up to optimum 'standoff' is discussed. The slant length of the liner is divided into n equal elements and the length of the jet ΔL arising from each element is calculated by eq. (8). ΔL from the first element near the apex of the liner (denote it by ΔL_1) will elongate to length dL_1 , just before striking the target. dL_1 can be calculated by eq. (9) in which p is put equal to zero. Depending on whether $dL_1 \leq$ or $> C\Delta L_1$, the primary penetration dP_1 by dL_1 length of the jet will be given by eq. (10a) or (10b) respectively. For calculating the length of the jet dL_2 arising from the second element of the conical liner the method is the same, except that in eq. (9) p is put equal to dP_1 and then dP_2 is calculated by eq. (10a) or (10b) depending whether

$dL_2 < \text{or} > C\Delta L_2$ respectively. Thus we calculate dP 's arising from different equal elements of the original liner and the sum will give the total primary penetration. The method takes into consideration the elongation of each element of the jet as it travels in space, the elongation which occurs as it penetrates the target and the strength of the target.

It is also possible to predict theoretically the dependence of the velocity of penetration or the time of penetration on the primary penetration. From eq. (1), we have

$$U = V \left(1 + \sqrt{\frac{\rho_T}{\lambda \rho_j}} \right) \quad \dots \quad (12a)$$

If $dL < C\Delta L$, the above equation reduces to

$$U = V \left(1 + \sqrt{\frac{\rho_T}{\rho}} \right) \quad \dots \quad (12b)$$

Hence for a fluid jet penetrating a target of the same material, the velocity of penetration for any element of the jet is one-half the velocity of the jet itself. If $dL > C\Delta L$, the eq. (12a) reduces to

$$U = V \left(1 + \sqrt{\frac{\rho_T dL}{\rho C \Delta L}} \right) \quad \dots \quad (12c)$$

The time required by each element to be fully used up is

$$dt = dP/U \quad \dots \quad (13)$$

Thus dt can be calculated for any element of the jet.

7. VOLUME OF THE HOLE.

Let dm represent the mass of the finite element MM' included between two planes perpendicular to the axis at x and x' . When it reaches the axis, it subtends a mean angle β with the axis and then is divided into two elements— dm_s and dm_j . The hydrodynamic theory of collapse of liner predicts that dm_j (the part of dm going into the jet) is given by the following expression:

$$\begin{aligned} dm_j &= dm \sin^2 \frac{\beta}{2} \\ &= \pi \tan \alpha \sec \alpha \eta \rho (x'^2 - x^2) \sin^2 \frac{\beta}{2} \quad \dots \quad (14) \end{aligned}$$

where η is the thickness of the wall of the original liner. For each element of the jet, dm_j and mean velocity are known, hence kinetic energy can be evaluated. The kinetic energy of an element of the jet is related to the volume of hole by eq. (4) and hence it is possible to calculate the increment in volume by each element of the jet as well as the profiles of hole in the given target.

8. MOMENTUM OF THE JET.

As the element ΔL of the jet travels, its length increases and the effective density decreases but the mass of the metal in that element of the jet dm_j and its mean velocity V remain constant; hence the momentum of that element must be constant and independent of the 'standoff'. The total momentum of the jet will also be constant and independent of the 'standoff' which agrees with the existing experimental data.

To illustrate the methods discussed above, a typical example is worked out and is given in the appendix.

ABSTRACT.

In a fundamental paper Birkhoff, MacDougall, Pugh, and Taylor (1948) presented hydrodynamic theories of jet formation and target penetration by explosives with lined conical cavities. Recently Pugh, Eichelberger, and Rostoker (1952) by assuming a variable instead of a constant collapse-velocity for the walls of the conical liner have explained the formation of the entire jet (including the 'after-jet') and the velocity gradient along it. The present note deals with the target penetration by a high-velocity jet when account is taken of the velocity gradient, the elongation of the jet and also of the strength of the target.

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APPENDIX.

(a) Calculated parameters of a given jet.

To illustrate the method of calculations an example is worked out. Eichelberger and Pugh (1952) have published the curves for V_j , V_0 and β as functions of x (curves extend up to 1.4 in.). The dimensions of the liner (the portion contributing towards the formation of the jet) taken for calculations are shown in Fig. 2. The values of V_j , V_0 and β as functions of x are tabulated in Table I.

TABLE I.
Values of V_j , V_0 and β as functions of x .*

x (cm.)	0.000	0.508	1.016	1.524	2.032	2.540	3.048	3.556
V_j (cm. $\times 10^5$ /sec.) ..	7.16	7.03	6.85	6.60	6.13	5.39	4.01	1.75
V_0 (cm. $\times 10^5$ /sec.) ..	2.76	2.71	2.64	2.59	2.55	2.40	2.19	1.41
β (degrees) ..	45	45	45	46	49	53	65	97

* The collapse parameters are taken by enlarging the curves published by Eichelberger and Pugh (1952).

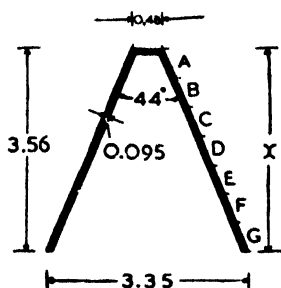


FIG. 2.

FIG. 2. Cross-section of the conical liner taken for calculations. (The dimensions are in cm.)

„ 3. Calculated correlation of the length of the jet and the velocity of its different elements at different times as it travels in space.

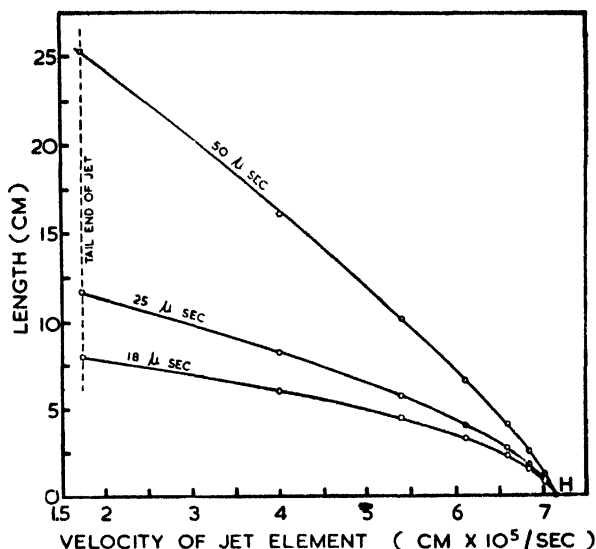


FIG. 3.

The curves of the velocity of penetration, time of penetration, increment of volume, etc. as functions of penetration (theoretical values) are presented in this appendix. In the curves, H represents the head of the jet and T the tail end of the jet.

Let D represent the calibre, i.e. the diameter of the base of the conical liner, that contributes towards the formation of the jet. For calculations, the values of the velocity of detonation U_d and density of the liner-metal are taken as 7.515×10^5 cm./sec. and 7.8 gm./c.c. respectively. The dynamic yield stress is taken as proportional to the static yield stress and the value taken is 3323×10^6 dynes/cm.². R is taken to be 6 times the yield stress.

(b) Length of the jet.

Let A, B, \dots, G represent different elements in the original conical liner from the apex to the base and each having a length $(0.508 \times \sec \alpha)$ cm. The jet is completely formed in 18μ sec., that is the time since the detonation wave passed the apex of the conical liner. The lengths of different elements of the jet dL_A, dL_B , etc., arising from the segments A, B , etc. at 18th μ sec., 25th μ sec. and 50th μ sec., are calculated and tabulated in Table II.

TABLE II.

Length of jet elements as these travel in space at different times.

Time	dL_A cm.	dL_B cm.	dL_C cm.	dL_D cm.	dL_E cm.	dL_F cm.	dL_G cm.	Total Length. cm.
18th μ sec.	0.70	0.77	0.80	0.98	1.20	1.50	1.98	7.93
25th μ sec.	0.78	0.90	0.97	1.31	1.71	2.46	3.55	11.68
50th μ sec.	1.10	1.36	1.59	2.50	3.54	5.92	9.20	25.21

The plot of the length of the jet against the velocity is shown in Fig. 3.

(c) *Penetration at different 'standoffs'.*

Let the penetration by successive elements of the jet dL_A , dL_B , etc. be dP_A , dP_B , etc. respectively. The total primary penetration by the jet at different 'standoffs' is calculated and tabulated in Table III.

TABLE III.

Calculated data of penetration at different 'standoffs'.

Standoff in units of charge diameters	Penetration in units of charge diameter
0	1.04
$\frac{1}{4}$	2.26
$\frac{1}{2}$	2.50
1	2.84
2	3.10
3	3.31
4	

The calculated primary penetration as a function of the 'standoff' is plotted in Fig. 4.

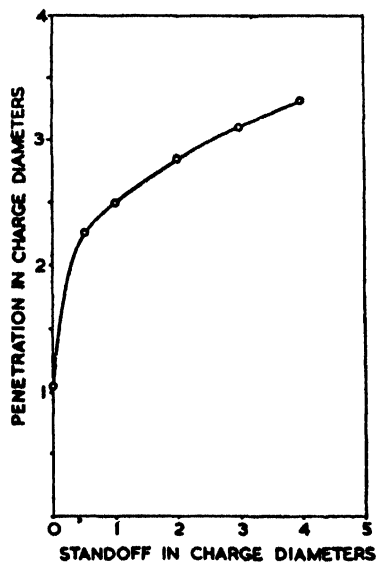


Fig. 4.

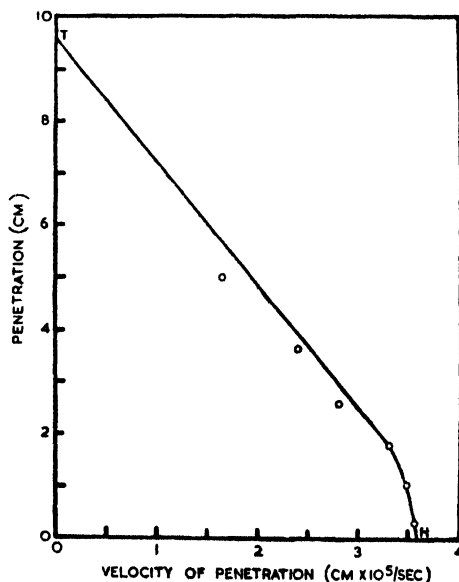


Fig. 5.

- Fig. 4. Calculated correlation of the primary penetration and the 'standoff' for the given jet.
 „ 5. Calculated correlation of the penetration (target at $2D$ 'standoff') and the velocity of penetration for the given jet.

(d) *Parameters of jet at 2D 'standoff'.*

The velocity of penetration U , time of penetration dt , mass of metal going into each element of the jet dm_j , increment in volume of the hole and radius of the hole are calculated, when a jet is penetrating a target at 2D 'standoff'. The calculated data are tabulated in Table IV.

TABLE IV.

Calculated parameters of the jet when the target is at 2D 'standoff'.

Parameters of jet	Segment of jet							Total
	dL_A	dL_B	dL_C	dL_D	dL_E	dL_F	dL_G	
dP (cm.) ..	0.66	0.75	0.77	0.88	1.16	1.57	3.73	9.52
U (cm. $\times 10^5$ /sec.) ..	3.55	3.47	3.28	2.81	2.39	1.66	1.12	..
dt (μ sec.) ..	1.86	2.17	2.34	3.13	4.83	9.47	33.44	57.24
dm_j (gm.) ..	0.12	0.20	0.28	0.39	0.54	0.84	1.69	4.06
Increment in volume (c.c.)	1.57	2.48	3.20	3.94	4.48	4.64	3.50	23.81
Radius of hole (cm.) ..	0.87	1.02	1.15	1.19	1.11	0.97	0.55	..

The penetration as functions of velocity of penetration, time of penetration and emergent velocity of the jet are plotted in Figs. 5 and 6. The velocity of the

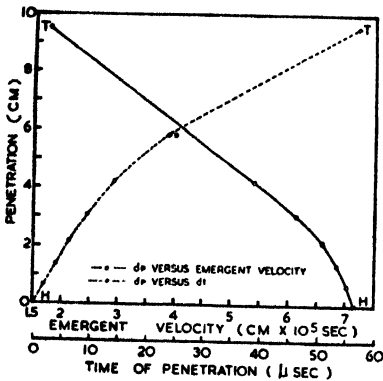


FIG. 6.

Fig. 6. Calculated correlation of the penetration (target at 2D 'standoff') versus the emergent velocity and the penetration versus the time of penetration for the given jet.

.. 7. Calculated correlation of the mass of metal in the unused jet and the velocity of the remaining jet as it is penetrating a target at 2D 'standoff'.

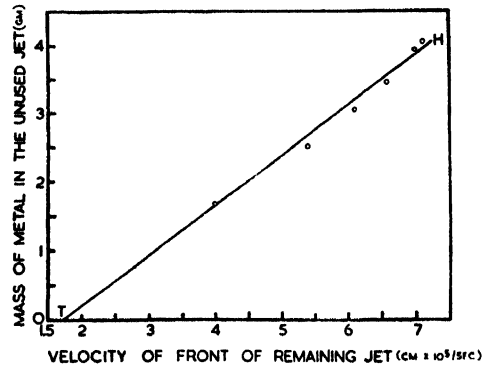


FIG. 7.

front of the remaining jet after penetrating dP and the mass of the metal in the unused jet are plotted in Fig. 7. This indicates that the jet while penetrating a target behaves as if there is uniform distribution of mass. An experimental verification of this conclusion has been published by Eichelberger and Pugh (1952). The increment in volume of hole as a function of depth of penetration is shown in Fig. 8. The calculated profiles of hole are shown in Fig. 9. This indicates that eq. (4) is applicable after the jet has penetrated about 1.5 cm., an assumption which is taken in deriving the eq. (4).

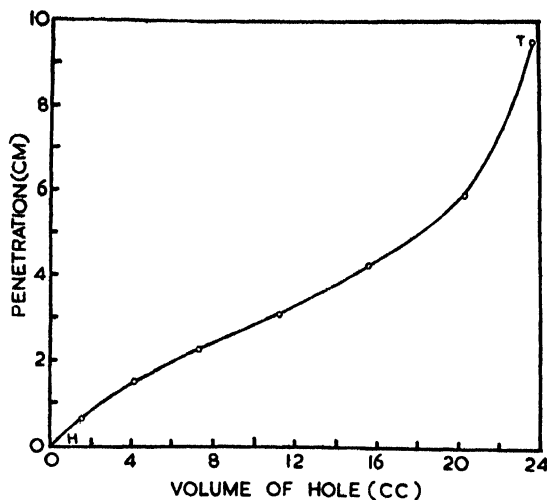


FIG. 8.

FIG. 8. Calculated correlation of the penetration (target at $2D$ 'standoff') and the volume of hole for the given jet.

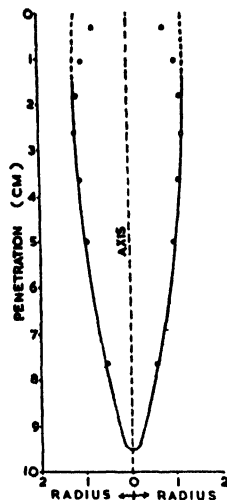


FIG. 9.

„ 9. Calculated profiles of the hole by the jet in a target at $2D$ 'standoff'.

Added in proof.

After sending this paper to press, the author received from Prof. E. M. Pugh the calculated collapse parameters for the given steel conical liner. This would mean minor changes in the numerical values given in Tables I to IV but the trend of the curves (Figs. 3 to 9) would remain unchanged.

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A NOTE ON GENTILE STATISTICS

by V. S. NANDA, *Delhi University, Delhi.*

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1. A new statistics intermediate between Bose-Einstein and Fermi-Dirac statistics was developed a few years ago by Gentile (1940). He regarded a single quantum cell in the phase space as capable of accommodating up to d particles. Using the method of most probable distribution he made a thermodynamic study of such an assembly. Gentile statistics, however, cannot have any physical significance, for it does not represent the behaviour of any realizable thermodynamic assembly. In fact, it can be shown by the theory of permutation groups that wave functions of quantum mechanics admit no symmetries other than those which lead to F.D. ($d = 1$) and B.E. statistics ($d = \infty$). Nevertheless, a study of Gentile statistics is not altogether without interest. It helped to focus attention on the failure of Darwin-Fowler method * in the degenerate B.E. case. Here we shall discuss an interesting problem which serves to bring out the point that the thermodynamic behaviour of an assembly depends primarily on the character of the wave function describing the assembly and not upon the maximum number of particles permitted to have the same energy.

2. For this purpose, we contemplate a particular Gentile assembly of N identical particles enclosed in a cube of volume L^3 . Then the number of states lying between ϵ and $\epsilon + d\epsilon$ is given by

$$a(\epsilon)d\epsilon = gD\epsilon^{\dagger} d\epsilon \quad \dots \quad (1)$$

where $D = \{2\pi L^3(2m)^{3/2}/h^3\}$ and g is the weight factor for the particle by virtue of its internal structure. For electrons $g = 2$, i.e., two electrons can have the same energy, provided their spins are oriented in the opposite direction. The question is whether it will make any difference if the electrons could possess the same energy by actually belonging to the same energy state. In other words, the problem is to study the difference between an actual electron assembly ($d = 1$, $g = 2$) and hypothetical assembly obtained by reversing the rôle of ' d ' and ' g ' for this assembly. We shall first evaluate the various thermodynamic functions and leave the physical discussion towards the end.

From the distribution law for a Gentile assembly

$$\bar{N}_r = \frac{1}{A^{-1}e^{\epsilon_r/kT} - 1} - \frac{d+1}{(A^{-1}e^{\epsilon_r/kT})^{d+1} - 1}, \quad \dots \quad (2)$$

we obtain for the number of particles N and energy E the expressions

$$N = \int_0^\infty \frac{a(\epsilon)d\epsilon}{A^{-1}e^{\epsilon/kT} - 1} - \int_0^\infty \frac{(d+1)a(\epsilon)d\epsilon}{(A^{-1}e^{\epsilon/kT})^{d+1} - 1} \quad \dots \quad (3)$$

$$E = \int_0^\infty \frac{\epsilon \cdot a(\epsilon)d\epsilon}{A^{-1}e^{\epsilon/kT} - 1} - \int_0^\infty \frac{\epsilon \cdot (d+1)a(\epsilon)d\epsilon}{(A^{-1}e^{\epsilon/kT})^{d+1} - 1}, \quad \dots \quad (4)$$

where the value of $a(\epsilon)d\epsilon$ is to be substituted from (1).

* See Schubert (1946).

3. Consider first the non-degenerate case which is characterized by $A \ll 1$. From equations (1) and (3) we obtain

$$N = D \left\{ \left(\frac{3}{2} \right) (kT)^{3/2} \right\} A + \frac{A^2}{2^{3/2}} + \left(\frac{1}{3^{3/2}} - \frac{1}{3^{1/2}} \right) A^3 + \dots \quad \dots \quad (5)$$

Defining now a quantity A_1 by

$$A_1 = \frac{N}{2 \left\{ \left(\frac{3}{2} \right) D (kT)^{3/2} \right\}}$$

one obtains on inversion from equation (5)

$$A = 2A_1 + 4aA_1^2 + 8bA_1^3 + \dots, \quad \dots \quad \dots \quad (6)$$

where

$$a = -\frac{1}{2^{3/2}}, \quad b = \frac{1}{4} + \frac{2}{3^{3/2}}.$$

Expanding equation (4) and substituting the value of A from (6) we obtain

$$E = \frac{3}{2} NkT \left\{ 1 + aA_1 + 4A_1^2 \left(b - a^2 - \frac{2}{3^{5/2}} \right) + \dots \right\}. \quad \dots \quad (7)$$

Making use of equations (6) and (7) other thermodynamic functions of interest can be evaluated. We have

$$\frac{G}{NkT} = \log A_1 + \log 2 + 2aA_1 + \dots \quad \dots \quad (8)$$

$$\frac{F}{NkT} = \log A_1 + \log 2 - 1 + aA_1 + \dots \quad \dots \quad (9)$$

$$\frac{S}{Nk} = -\log A_1 + \frac{5}{2} - \log 2 + \frac{a}{2} A_1 + \dots \quad \dots \quad (10)$$

where G , F and S denote Gibb's free energy, Helmholtz's free energy and the entropy respectively.

For the sake of comparison the thermodynamic functions of an electron assembly will now be given and these will be distinguished from the previous case by using a suffix e . We have on putting $S = 3/2$ in Singh's (1941) paper

$$E_e = \frac{3}{2} NkT \left\{ 1 + \frac{A_1}{2^{5/2}} + A_1^2 \left(\frac{1}{2^2} - \frac{2}{3^{5/2}} \right) + \dots \right\} \quad \dots \quad (7a)$$

$$\frac{G_e}{NkT} = \log A_1 + \frac{A_1}{2^{3/2}} + \dots \quad \dots \quad (8a)$$

$$\frac{F_e}{NkT} = \log A_1 - 1 + \frac{A_1}{2^{5/2}} + \dots \quad \dots \quad (9a)$$

$$\frac{S_e}{Nk} = -\log A_1 + \frac{5}{2} - \frac{A_1}{2^{7/2}} + \dots \quad \dots \quad (10a)$$

4. In the strongly degenerate case $A \gg 1$. The Gentile integrals for this case can be evaluated by the following procedure :—

Let

$$f(\alpha) = \int_0^\infty \frac{\phi'(x)}{e^{x-\alpha} - 1} dx.$$

If $\omega = u + iv$ and $0 < v < 1$ we have

$$\int_{-\infty}^{+\infty} e^{-\omega\alpha} f(\alpha) d\alpha = \int_{x=0}^{\infty} \int_{y=-\infty}^{+\infty} \phi'(x) \frac{e^{-(x+y)\omega}}{e^{-y}-1} dx dy.$$

Now
$$\int_{-\infty}^{\infty} \frac{e^{-\omega y}}{e^{-y}-1} dy = \pi \cot \pi\omega, \text{ therefore}$$

$$\int_{-\infty}^{\infty} e^{-\omega\alpha} f(\alpha) d\alpha = \pi \cot \pi\omega \int_{x=0}^{\infty} e^{-\omega x} \phi'(x) dx.$$

Applying the formula of Laplace transform

$$f(\alpha) = \frac{1}{2i} \int_{\gamma-i\infty}^{\gamma+i\infty} e^{-\omega\alpha} \cot \pi\omega \Phi(\omega) d\omega,$$

where

$$0 < \gamma < 1 \text{ and } \Phi(\omega) = \int_0^{\infty} e^{-\omega x} \phi'(x) dx.$$

Noting that

$$\cot \pi\omega = \frac{1}{\pi\omega} \left\{ 1 - \sum_{n=1}^{\infty} D_n \omega^{2n} \right\},$$

where $D_n = (2\pi)^{2n} B_n / (2n)!$ and by following the procedure similar to that of Auluck (1942) in the case of Fermi integrals we get

$$f(\alpha) \simeq \phi(\alpha) - \sum_{n=1}^{\infty} D_n \phi^{2n}(\alpha). \quad \dots \dots \dots (11)$$

Here we are faced with integrals of the type

$$F(\alpha) = \int_0^{\infty} \frac{\phi'(x) dx}{e^{x-\alpha}-1} - \int_0^{\infty} \frac{(d+1) \phi'(x)}{e^{(d+1)(x-\alpha)}-1} dx.$$

Making use of (11) we have

$$F(\alpha) = d\phi(\alpha) + \sum_n \left(1 - \frac{1}{(d+1)^{2n-1}} \right) D_n \phi^{2n}(\alpha).$$

Equation (3) then becomes

$$N = \frac{2}{3}(dg)\alpha_0^{3/2} \left\{ 1 + \frac{\pi^2}{4(d+1)\alpha_0^2} + \frac{\pi^4}{80} \frac{d^2+3d+3}{(d+1)^3\alpha_0^4} + \dots \right\} \dots \quad (12)$$

For the case $d = 2$ and $g = 1$

$$\alpha_0 = \log A = (A_1 | \frac{1}{2})^{2/3} \left\{ 1 - \frac{\pi^2}{18} (A_1 | \frac{1}{2})^{-4/3} \dots \right\}. \quad \dots \quad (13)$$

Using (12) and (13) we can expand (4) in the form

$$\frac{E}{NkT} = \frac{3}{5} (A_1 |\bar{\epsilon}|)^{2/3} \left\{ 1 + \frac{5}{8} \pi^2 (A_1 |\bar{\epsilon}|)^{-4/3} + \dots \right\} \quad \dots \quad (14)$$

Also

$$\frac{G}{NkT} = \log A = (A_1 |\bar{\epsilon}|)^{2/3} \left\{ 1 - \frac{\pi^2}{18} (A_1 |\bar{\epsilon}|)^{-4/3} + \dots \right\} \quad \dots \quad (15)$$

Hence

$$\frac{F}{NkT} = \frac{3}{5} (A_1 |\bar{\epsilon}|)^{2/3} \left\{ 1 - \frac{5}{8} \pi^2 (A_1 |\bar{\epsilon}|)^{-4/3} + \dots \right\} \quad \dots \quad (16)$$

and

$$\frac{S}{Nk} = \frac{\pi^2}{3} (A_1 |\bar{\epsilon}|)^{-2/3} + \dots \quad \dots \quad (17)$$

The case ($d = 1$, $g = 2$) of the electron assembly can be similarly treated. But the expressions for the thermodynamic functions can also be obtained from Singh's paper (*loc. cit.*) as before by putting $S = 3/2$.

We have

$$\frac{E_*}{NkT} = \frac{3}{5} (A_1 |\bar{\epsilon}|)^{2/3} \left\{ 1 + \frac{5}{8} \pi^2 (A_1 |\bar{\epsilon}|)^{-4/3} + \dots \right\} \quad \dots \quad (14a)$$

$$\frac{G_*}{NkT} = (A_1 |\bar{\epsilon}|)^{2/3} \left\{ 1 - \frac{\pi^2}{12} (A_1 |\bar{\epsilon}|)^{-4/3} + \dots \right\} \quad \dots \quad (15a)$$

$$\frac{F_*}{NkT} = \frac{3}{5} (A_1 |\bar{\epsilon}|)^{2/3} \left\{ 1 - \frac{5}{8} \pi^2 (A_1 |\bar{\epsilon}|)^{-4/3} + \dots \right\} \quad \dots \quad (16a)$$

$$\frac{S_*}{Nk} = \frac{\pi^2}{2} (A_1 |\bar{\epsilon}|)^{-2/3} + \dots \quad \dots \quad (17a)$$

5. It will be seen from equations (7) to (10) and (7a) to (10a) that in the classical case, which is characterized by $A \rightarrow 0$, the results obtained for the two assemblies are similar. Physically the reason is that the quantum cells are so numerous that most of them lie vacant most of the time. The probability of a cell being occupied by two particles at the same time is negligible. So it does not matter whether two particles are allowed in the same energy state or not. With A finite, but still small, the difference in behaviour sets in. The energy of the assembly to a first approximation is the same but other thermodynamic functions differ by a factor $\log 2$. The root cause for this is of course the entropy which is greater for an actual electron assembly than for the Gentile case.*

In the strongly degenerate case ($A \gg 1$) all the thermodynamic functions except entropy are to a first approximation the same. The reason is obvious. Here (TS) has become very small as compared to E which at low temperatures is

* Intuitively this can be verified by making use of the relationship between the problems in statistical thermodynamics and the partition theory of numbers. The electron assembly corresponds to the case where in a partition the repetition of summands is not permitted but each summand can occur in two different ways. In the Gentile case, each summand can occur twice in a partition. The former would obviously give larger number of partitions (i.e. greater entropy for the corresponding assembly) than the latter one.

large due to the existence of the zero point energy. The latter quantity being the same for the two assemblies, the thermodynamic functions become exactly equal in the completely degenerate case.

I would like to record my thanks to Prof. D. S. Kothari for suggesting the problem and to Dr. F. C. Auluck for many helpful discussions.

SUMMARY.

In the intermediate statistics of Gentile at most d particles can occupy the same energy state. A seemingly similar situation is obtained for a Fermi-Dirac assembly ($d = 1$) by making the energy levels d -fold degenerate ($g = d$). A comparison of the thermodynamic behaviour of the two assemblies (where the rôle of d and g is reversed) is made. Such an investigation brings out clearly the point that the thermodynamic behaviour of an assembly depends on the character of the wave function describing the assembly and not upon the maximum number of particles which are allowed to have the same energy.

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ON THE ZEROS OF A CLASS OF POLYNOMIALS

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1. In this paper we prove certain results concerning the zeros of a class of polynomials.

THEOREM 1. Let $P(z) = \sum_{v=0}^n a_v z^v$ be a polynomial with real or complex coefficients such that for $n \geq 2$

$$|a_0| + |a_1| + \dots + |a_{n-1}| \leq n|a_n| \quad \dots \quad \dots \quad \dots \quad (1.1)$$

$$2^{\frac{n+1}{2}} r^n (n+1) \left| \frac{a_n}{a_0} \right| < 1 \quad \dots \quad \dots \quad \dots \quad \dots \quad (1.2)$$

$$r > \frac{1}{2} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (1.3)$$

Then at least one zero of $P(z)$ lies outside the circle $|z| = r$.

Remark: Conditions (1.1) to (1.3) are consistent; as an example we can take

$$P(z) = 6z^3 + 2z^2 + z + 13 \text{ and } r = \frac{1}{2}.$$

For the proof we require the following lemma due to Bernstein (V. Bernstein, 1934; M. L. Cartwright, 1935).

Lemma: If $F(z)$ is regular for $|z| \leq R$ and that

$$\log |F(0)| > -A$$

$$\log |F(z)| < A \text{ for } |z| \leq R$$

then $n(r) \leq 2A / \log \left(\frac{R}{r} \right)$ where $n(r)$ is the number of zeros of $F(z)$ for $|z| \leq r < R$.

Proof of Theorem 1: Let $R \geq 1$

$$\begin{aligned} \max_{|z|=R} \left| \frac{P(z)}{a_0} \right| &< \left| \frac{a_n}{a_0} \right| R^n + \left| \frac{a_{n-1}}{a_0} \right| R^{n-1} + \dots + \left| \frac{a_1}{a_0} \right| R + 1 \\ &< \frac{R^n}{|a_0|} \{ |a_n| + \dots + |a_0| \} \\ &< (n+1) R^n \frac{|a_n|}{|a_0|}. \end{aligned}$$

Now put

$$R = 2r, \quad r > \frac{1}{2}.$$

Then

$$\begin{aligned} \max_{|z|=2r} \left| \frac{P(z)}{a_0} \right| &< (n+1) \frac{|a_n|}{|a_0|} 2^n r^n \\ &< 2^{\frac{n-1}{2}} \end{aligned}$$

Hence by the Maximum modulus theorem

$$\left| \frac{P(z)}{a_0} \right| < 2^{\frac{n-1}{2}} \text{ for } |z| \leq 2r$$

and so
$$\log \left| \frac{P(z)}{a_0} \right| < \frac{n-1}{2} \log 2 \text{ for } |z| \leq 2r$$

Further
$$\log \left| \frac{p(0)}{a_0} \right| = 0 > -\frac{n-1}{2} \log 2$$

Hence from the lemma $n(r) \leq (n-1)$ which proves the theorem.

THEOREM 2. If in
$$P(z) = \sum_{\nu=0}^n a_{\nu} z^{\nu}$$

$$\text{Min}_{\nu=0}^n \left\{ |a_{\nu}| \right\} > 1$$

and
$$\text{Max}_{\nu=0}^{n-1} \left\{ |a_{\nu}| \right\} > |a_n|$$

then
$$n \left(\frac{R}{k} \right) < \frac{2 \log \left\{ (n+1) |a_n| R^n \right\}}{\log k}, \quad (k > 1)$$

where
$$R = \text{Max} \left\{ \left| \frac{a_{n-1}}{a_n} \right|, \left| \frac{a_{n-2}}{a_n} \right|^{\frac{1}{2}}, \left| \frac{a_{n-3}}{a_n} \right|^{\frac{1}{3}}, \dots \right\}$$

$n(x)$ denoting the number of zeros of $P(z)$ in $|z| \leq x$.

The proof of the above theorem is straightforward, for under the conditions stated $|a_n| |z|^n$ is the maximum term of the polynomial, so

$$\text{Max}_{|z|=R} |P(z)| < (n+1) |a_n| R^n$$

and hence by the Maximum modulus theorem for $|z| \leq R$ also.

Further $\log |P(0)| > 0$ and under the hypothesis $(n+1) |a_n| R^n > 1$, hence the conditions of Bernstein's lemma are satisfied and using it we get the result.

THEOREM 3. Let the coefficients of $P(z) = \sum_{\nu=0}^n a_{\nu} z^{\nu}$ be such that

$$\left| \frac{a_{n-1}}{a_n} \right| > \text{Max} \left\{ \left| \frac{a_{n-2}}{a_n} \right|^{\frac{1}{2}}, \left| \frac{a_{n-3}}{a_n} \right|^{\frac{1}{3}}, \left| \frac{a_{n-4}}{a_n} \right|^{\frac{1}{4}}, \dots \right\} \quad \dots \quad (1.4)$$

then all the zeros of $P(z)$ lie inside the circle $|z| < 2 \left| \frac{a_{n-1}}{a_n} \right|$.

Proof: Let $\left| \frac{a_{n-1}}{a_n} \right| = R$

and let $P(Z_0) = 0$,

then it is sufficient to prove that $|Z_0| = R_1 < 2R$.

Now
$$|a_n|R_1^n < |a_{n-1}|R_1^{n-1} + |a_{n-2}|R_1^{n-2} + \dots + |a_0|$$

so
$$1 < \left\{ \frac{R}{R_1} + \left(\frac{R}{R_1} \right)^2 + \dots + \left(\frac{R}{R_1} \right)^n \right\}$$

hence
$$1 < \frac{\frac{R}{R_1} \left\{ 1 - \left(\frac{R}{R_1} \right)^n \right\}}{1 - \frac{R}{R_1}}.$$

Now if $1 - \frac{R}{R_1}$ is negative then $R > R_1$ and hence *a fortiori* $R_1 < 2R$ and if $1 - \frac{R}{R_1}$ is positive, then we can multiply both the sides by it and we get

$$1 + \left(\frac{R}{R_1} \right)^{n+1} < 2 \frac{R}{R_1}$$

which gives

$$R_1 < 2R.$$

2. Let $S_n(z) = 1 + z + \frac{z^2}{2!} + \frac{z^3}{3!} + \dots + \frac{z^n}{n!}$ we have,

THEOREM 4. Corresponding to any circle $|z| = r$ we can always, for $n > n_0$, find a sub-sequence $S_{n_1}(z), S_{n_2}(z), \dots$ such that all the zeros of this sub-sequence lie outside the circle $|z| = r$.

Proof: Here the limiting function of the sequence $\{S_n(z)\}$ is e^z . Take a region Γ in the finite z -plane and let z_0 be its any interior point. Enclose z_0 by means of a small circle lying wholly within Γ . Then by Hurwitz's theorem (Titchmarsh, 1939) we can always find out a sub-sequence formed from the sequence $\{S_n(z)\}$ such that all its zeros lie outside $|z| = r$ if we choose r suitably lying entirely within Γ ; for if it were not possible, then z_0 will be a limit point of the sequence $\{S_n(z)\}$. So by the theorem of Hurwitz, it will be a zero of e^z , which is not true as e^z has no zeros.

SUMMARY.

In this paper by applying Bernstein's lemma and Hurwitz's theorem we have proved results about the zeros of a class of polynomials.

ACKNOWLEDGEMENT.

Finally, I take this opportunity to thank Dr. S. M. Shah for his help in the preparation of this paper.

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PTILOPHYLLUM AMARJOLENSE, SP. NOV. FROM THE RAJMAHAL
HILLS, BIHAR,

by M. N. BOSE, *Birbal Sahnii Institute of Palaeobotany, Lucknow.*

(Communicated by T. S. Mahabale, F.N.I.)

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INTRODUCTION.

The generic name *Ptilophyllum* was first used by Morris in 1840 for certain pinnate fronds from Cutch, India, which he described under the species *P. cutchense*. In 1863 Oldham and Morris adopted the name *Palaeozamia* for similar fronds. Later Feistmantel (1876, 1877) reported a number of species of *Ptilophyllum* from various localities in India. In 1900 Seward described a Cycadean trunk to which leaves of the type of *Ptilophyllum cutchense* were found in organic connection. Bancroft (1913) described from the Rajmahal Hills, two species of *Ptilophyllum*: *P. cutchense*, Feistmantel and *P. acutifolium* (Oldham and Morris). In 1917 Seward summarized the earlier works on *Ptilophyllum* and later with Sahnii (1920) worked on a large collection of *Ptilophyllum* and combined all the previous species of *Ptilophyllum* and *Palaeozamia* describing them under an aggregate species, *P. acutifolium* Morris. In 1931 Sahnii and Rao described three distinct species, *P. cf. cutchense* McCl. sp., *P. acutifolium* Morris sp. and *P. tenerrimum* Feistmantel from a collection from the Rajmahal Hills. Ganju in 1946 recognized four species of *Ptilophyllum* from Onthea: *P. cf. cutchense* McCl. sp., *P. acutifolium* Morris sp., *P. sp. A*, and *P. sp. B*. The latest mention of *Ptilophyllum cutchense* is by Rao (1948), who has studied the internal anatomy of the pinnae.

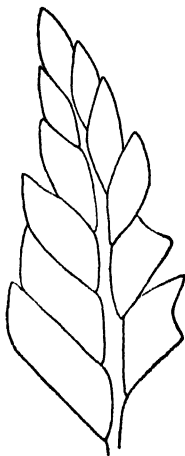
The material here described was collected in November, 1950 and May, 1951 from Amarjola, a fossil locality in the District of Amrapara, Rajmahal Hills, Bihar. In all about one hundred petrified fragments of detached leaves were obtained. Only one of the leaves collected is complete with the petiole. Along with the leaves a few detached petioles have also been collected. The present fronds have been collected in association with a new species of *Bucklandia* (*B. Sahnii* Bose) from the same locality. The other plant fossils occurring in the locality are *Williamsonia*, *Pentoxylon Sahnii*, *Homoxylon rajmahalense*, *Brachyphyllum*, *Coniferocaulon*, and many other coniferous woods.

So far cuticular preparations could not be successfully made. The surface structure has therefore been studied under a strong reflected light. Sections of the petiole, rachis and pinnule have been prepared after embedding the material in a kind of plastics obtained from the market under the commercial name 'Marco resin'.

DESCRIPTION.

The length of the leaf could not be determined as none of the leaves collected are complete with its petiole and apex. The fragments belong mostly to the middle part. Only two specimens representing the apical regions of the leaves have been collected (Pl. XXVII, fig. 13), and one of the fragments shows the basal portion (Pl. XXVII, fig. 15). The width of the leaves is variable from about 0.4 cm. to 4.5 cm. but the majority measure from 1 cm. to 1.5 cm. Lamina as a whole has even

width, tapering very gradually below and more suddenly at the apex. The leaves are imparipinnate (Text-fig. 1).



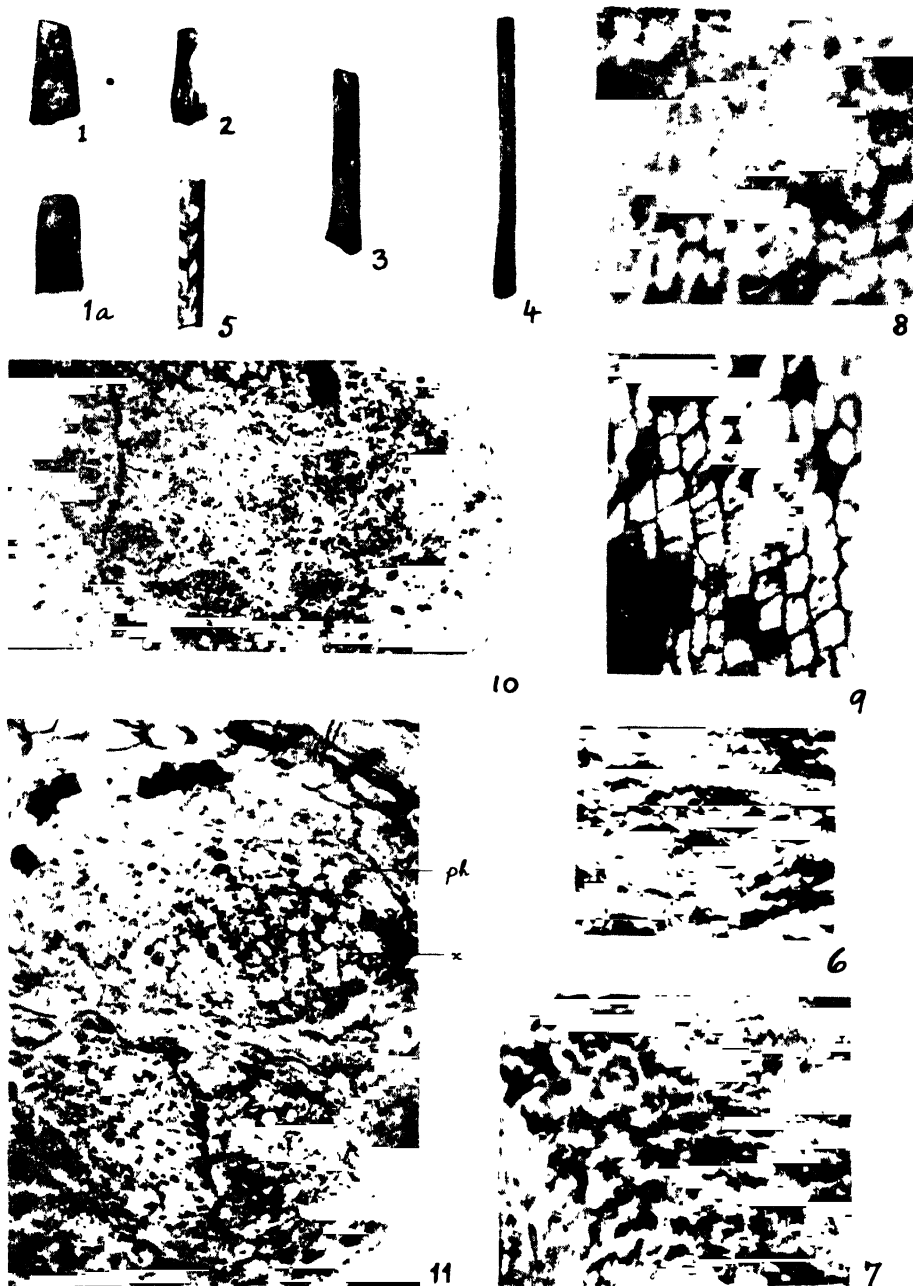
TEXT-FIG. 1. An apical region of a leaf. ($\times 5$.)

Petiole.

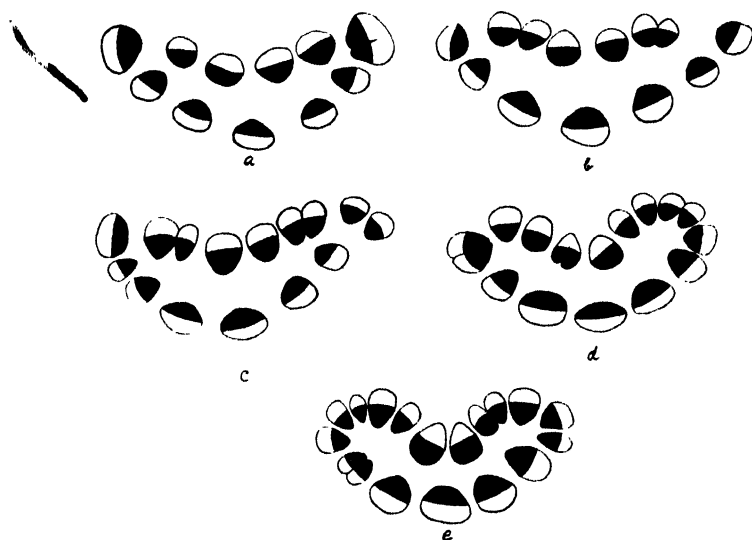
A petiole is expanded at the lower end to form a pulvinus (Pl. XXVI, figs. 1, 2). The pulvinus ranges in diameter from 0.3 cm. to 1 cm.; it is thick in the middle and thin towards the edges. The first sign of pinnæ arising is seen approximately at a distance of 2.5 cm. to 3 cm. (Pl. XXVI, fig. 4) from the pulvinus. The upper surface of the pulvinus shows a few prominent longitudinal ridges running parallel to each other while the lower surface is much wrinkled. The epidermal cells on the ventral side of the base of the pulvinus are rectangular and very much elongated in surface view, but suddenly become much smaller (Pl. XXVI, fig. 8) with uneven walls towards the rachis (about 2 cm. above the leaf base). The wall of the epidermal cells appear as if possessing a series of swellings. Such epidermal cells are found throughout the length of the rachis both on the upper and lower surfaces. On the dorsal surface of the pulvinus a peculiar pattern of elongated cells is seen mixed with patches of round cells. Mostly round cells are found on the ridges of wrinkles with the elongated cells between the ridges. Stomata are absent on both the surfaces.

A transverse section at the base of the petiole is more or less oval, with dorsal side more convex than the ventral. The cells of the epidermis are rectangular and more broad than high. The hypodermal zone is 6-7 cells wide and consists of mostly thick-walled hexagonal sclerenchymatous cells. The cells on the abaxial side are, however, longer than those on the adaxial side. The ground tissue consists of loosely connected isodiametric cells. These cells on the inner side towards the phloem region of the bundles tend to become oval. There are a number of collateral vascular bundles arranged in a kidney-shaped fashion (Pl. XXVI, fig. 10). The maximum number of bundles counted is eleven. The xylem and phloem in a bundle are practically developed to the same extent and the xylem in all the bundles is pointing inwards. The xylem tracheids are quadrangular to hexagonal. In a radial section towards the base of the petiole the secondary walls of the tracheids are marked by spiral thickenings while higher up towards the rachis the thickening is scalariform. The phloem is not well preserved, the cells are mostly polygonal in outline.

The course of the bundles could not be studied clearly. As has been mentioned earlier the minimum number of bundles counted is eleven that is at the very base



of the petiole. They are arranged in a kidney-shaped fashion. Of these bundles five are abaxial, two lateral and four adaxial. Further up the bundles divide very rapidly and generally split into two. Division is first seen in the lateral bundles (Text-figs. 2a-2e), then it seems there is more rapid division of the bundles on the ventral side which move inwards towards the dorsal side until higher up in the rachis there is a double series of bundles in the form of 'U'.



TEXT-FIGS. 2a-e. Outline drawings showing course of the leaf-trace bundles. Xylem shown black and phloem region of each bundle is left blank. ($\times 10$.)

Rachis.

The major portion of the rachis is concealed by the pinnae which are attached to the upper surface. The epidermal cells over the whole length of the rachis are rectangular and have the same kind of swellings found in the epidermal cells on the upper region of the petiole (Pl. XXVI, fig. 9).

The transverse section of the rachis shows an upper layer of epidermal cells, which are rectangular in outline. The hypodermis which follows the epidermis is of about 6 to 7 cells in thickness. Both the epidermal and hypodermal cells are identical to those found in the petiole. The ground tissue consists of isodiametric or oval cells and have sometimes intercellular spaces between them. The vascular bundles are arranged in a double series in the form of 'U' (Pl. XXVIII, fig. 21). The maximum number of bundles counted is 46, or may be even more. The xylem in all the bundles is pointing inwards (Pl. XXVIII, figs. 22, 23). The xylem elements show scalariform thickenings on their radial walls (Pl. XXVIII, fig. 24). The cells of the phloem are polygonal in outline. They are mostly not well preserved.

Pinnae.

The pinnae almost touch each other and vary little in shape, but the variation is found only in the apical regions of the fronds. They are 0.2 cm. to 0.5 cm. broad, mostly oblong, short and have rounded apices. In the apical regions and also in the middle of the fronds, the pinnae are slightly falcate with more or less acute tips. The upper basal corners of the pinnae are rounded while the lower basal angles are not rounded. Upper surface of pinnae is smooth and shows very fine striations,

whereas the lower side shows the veins which are distant, nearly parallel, and branching at all levels (Text-figs. 3a-3f). Even in the same leaf there are variations in the mode of branching of the veins in individual pinnae.

The epidermal cells on the upper surface of the pinnae are very much elongated (Pl. XXVII, fig. 17). The stomata are absent on this surface. The lower surface shows 3 to 4 rows of much elongated epidermal cells over each vein and at the point of bifurcation even up to 6 rows have been met with (Pl. XXVII, figs. 18, 19, 20). Epidermal cells between the veins are irregular in shape with thin sinuous walls. The walls have a few folds. The bands between the veins are packed with stomata orientated more or less at right angles to the veins. In crossing each vein 2 to 4 stomata are met with, usually 3, very rarely 5. The average dimensions of the guard cells are 43μ by 34μ . Stomata have fairly broad subsidiary cells.

The cross-section of a pinna shows an upper layer of rectangular cells which are very small, lined by a single layer of hypodermis both on the upper and lower side. The cells of the hypodermis are much thickened and are bluntly tapering inwards (Pl. XXVIII, fig. 26). A layer of narrow and elongated palisade cells follows the hypodermis. The spongy mesophyll is generally not well preserved and quite loose. The vascular bundles are situated between the mesophyll and the lower hypodermis. No details are seen in bundles. The xylem is situated on the upper side and the phloem on the lower side. Stomata are not distinctly seen on the lower epidermis in cross-section.

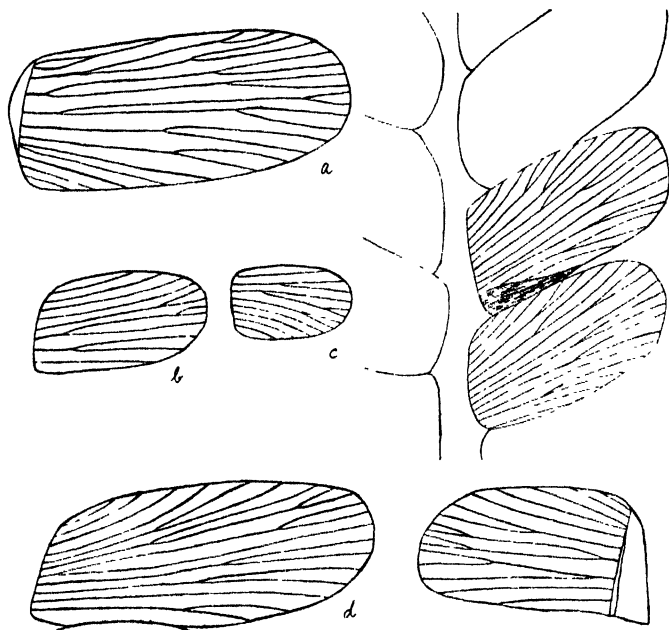
COMPARISON AND DISCUSSION.

Leaves.—Morris in 1840 first founded the genus *Ptilophyllum* for certain pinnate fronds from Cutch, India, based upon the following characters (Seward, 1917, p. 512): 'Fronds pinnate; pinnae closely approximated, linear, lanceolate, more or less elongate, imbricate at the base, attached obliquely; base semicircular or rounded; veins equal, slender, parallel.' There are very few Indian species of *Ptilophyllum* of which the cuticle structure is known and even in these cases it is known partly. The structure of *Ptilophyllum* was described to some extent by Bancroft in 1913. She described two species: *P. cutchense* Feistmantel, and *P. acutifolium* (Oldham and Morris), differing mainly on the external characters of pinnae; *P. cutchense* having short oblique pinnae with rounded apices and *P. acutifolium* having longer narrower pinnae with acute apices, subauriculate at the upper basal angle and decurrent at the lower. In a cross-section of the rachis of *Ptilophyllum cutchense*, as in *P. amarjoleense*, the vascular bundles are arranged in the form of 'U'. The structure of the pinnae of *P. cutchense* is very like *P. amarjoleense* in external form and internal structure but *P. amarjoleense* differs from the former in having also pinnae with acute tips like those of *P. acutifolium*.

Sahni and Rao (1931) working on a collection of plants from the Rajmahal Hills recognized three distinct species of *Ptilophyllum*. One of them was *P. cf. cutchense* McCl. sp. This name was adopted for the type of fronds corresponding to those found in association and attached to the stem *Bucklandia indica* Seward. These have short pinnae with round apices, the under surfaces show four rows of epidermal cells over each vein. Stomata are placed longitudinally between the bands of the veins and in crossing each band 2 to 3 of them are met with. Sahni in 1932 reconstructed the plant *Williamsonia Sewardiana* having the stem *Bucklandia indica* Seward, the leaves *Ptilophyllum cf. cutchense* and the flower *W. Sewardiana*. Further studies on *P. cf. cutchense* collected from Onthea were made by Ganju in 1946. He observed three rows of elongated epidermal cells over each vein. Majority of the fronds of *P. amarjoleense* resemble *P. cf. cutchense* in having short pinnae with rounded apices and in the nature of the epidermal cells over each vein. *P. amarjoleense*, however, differs from *P. cf. cutchense* in having a very variable width of the lamina and having slightly falcate pinnae at the apical region of the



frond and also in the widest fronds. Although *P. amarjolense* includes two types of pinnae yet their epidermal character and anatomy are exactly similar. Hence they have to be included under one species. Moreover, *P. amarjolense* has been found in association with a new species of *Bucklandia*, *B. Sahnii* Bose, whereas *P. cf. cutchense* has been referred to *B. indica*.



TEXT-FIGS. 3a-f. Some of the pinnules showing mode of branching of the veins. ($\times 5$.)

The pinnae at the apical region and of the widest fronds of *P. amarjolense* resemble *P. acutifolium* in external form. In both these the fronds have long and acutely pointed pinnae. *P. acutifolium* is said to be subauriculate at the upper basal angle and decurrent at lower, whereas in *P. amarjolense* the pinnae have rounded upper basal corner and they are not decurrent. Seward and Sahni (1920) were the first to describe the cuticle of *P. acutifolium* agg. sp. sens. lat. It has numerous stomata on the lower side which are placed transversely to the long axis of the pinna, similarly in *P. amarjolense* the stomata are found packed in between the veins and they are arranged at right angles to the veins. In *P. acutifolium* agg. sp. the epidermal cells both on the upper and the lower surfaces, have sinuous walls, whereas in *P. amarjolense* the epidermis on the upper surface have elongated cells and on the lower surface they have sinuous walls but less folded than those in *P. acutifolium*. Ganju in 1946 described *P. acutifolium* Morris from Onthea. These like *P. amarjolense* have 4 rows of epidermal cells over each vein. But in *P. amarjolense* in crossing each vein 2 to 4 stomata are met with whereas in *P. acutifolium* 3 to 5 are seen.

P. tenerrimum Feistmantel, described by Sahni and Rao in 1931, is based only on external form and is different from *P. amarjolense*, as in the former the pinnae are very narrow and straight.

From the above description of the different species of *Psilophyllum*, it is seen that the species are mainly based on the external form of the pinna and the cuticles of most of the leaves are only partly known. The description of *P. amarjolense* is fairly complete and it includes both the type of pinnae found in *P. cf. cutchense* and

P. acutifolium. The present species resembles very much *P. cf. cutchense* McCl. sp. in external form and to some extent in surface structure. Also the wider fronds of *P. amarjolense* show similarity with *P. acutifolium*, but they differ greatly in the nature of the epidermal cells.

There are some foreign species of *Phyllophyllum* which shows a striking resemblance with some of the wider fronds of *P. amarjolense* so far as the form of the fronds and pinnae is concerned. *P. amarjolense* resembles *P. caytonense* Harris (1942), in the form of its pinnae, but *P. amarjolense* has more crowded stomata on the lower surface and on the upper surface the epidermal cells are much elongated, whereas, in *P. caytonense* the upper epidermis shows cells with very sinuous walls. *P. pectinoides* described by Harris (1946), agrees to some extent with *P. amarjolense* in the external form of the leaf and pinnae and in lacking mushroom-shaped cells. *P. amarjolense*, however, differs from *P. pectinoides* in having much more crowded stomata on the lower surface. The epidermal cells on the upper surface of these are very different from each other. *P. pecten* Phill., as described by Thomas and Bancroft (1913), resembles *P. amarjolense* in external form of leaf to some extent only. It is well distinguished by its less numerous stomata and cells with sinuous walls on the upper epidermis. *P. pecten* (Phillips) Morris and *P. sp.* of Oishi (1940); *P. pecten* of Walkom (1917), also show similarity in the form of fronds and pinnae. *P. sp.* Oishi resembles the smaller fronds of *P. amarjolense* in having pinnae with rounded apices. The cuticles of these specimen are not known.

Petiole.—In its anatomy the petiole closely resembles the bracts of the flower *Williamsonia Sewardiana* Sahnii and the leaf-bases of the stem *Bucklandia Sahnii* Bose. In *W. Sewardiana* and the leaf-bases of *B. Sahnii* there is an outer layer of epidermis which is followed by a hypodermal zone of sclerenchyma and the cells of the hypodermis are thick-walled. In *W. Sewardiana* there are usually 7 collateral bundles, sometimes even 10 or 11 are met with. The maximum number of bundles counted in the basal region of the petiole is 11. In the leaf-bases of *B. Sahnii* there are 5 such bundles, rarely 7. Also, both in the leaf-bases of *B. Sahnii* and the petiole of *P. amarjolense* the tracheids have spiral thickenings on their radial walls. *P. amarjolense* as stated earlier has been collected in association with the stem *B. Sahnii* and the very close similarity between the anatomy of the petiole of this leaf and the leaf-bases of *B. Sahnii* suggests the possibility that these fronds were borne on the stem *B. Sahnii*.

ABSTRACT.

The present paper describes the epidermal characters and internal anatomy of a new species of *Phyllophyllum*, *P. amarjolense*, collected from the Jurassic of Amarjola in the District of Amrapara, Rajmahal Hills, Bihar. The leaves collected are all fragmentary and detached from the main stem. The anatomy of the petiole is similar to that of leaf-bases of *Bucklandia Sahnii* Bose. The rachis in cross-section shows the vascular bundles arranged in a double series in the form of 'U'. The leaves have a variable width, about 0.4 cm. to 4.5 cm. wide. The pinnae are mostly oblong, short and have a rounded apex, but at the apical region and in the widest fronds they are slightly falcate with acute apex. Epidermal cells on the upper side are much elongated, lower side has thin-walled sinuous cells with numerous stomata transversely orientated in the bands between the veins. Three to four rows of elongated epidermal cells are found over each vein. The pinnae show an upper epidermis followed by hypodermis, palisade and spongy-mesophyll tissues. Vascular bundles are situated in between the mesophyll and the lower hypodermis.

The closest resemblance of the frond is with *P. cf. cutchense*.

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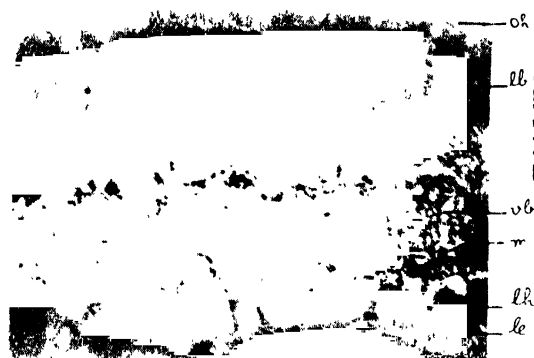
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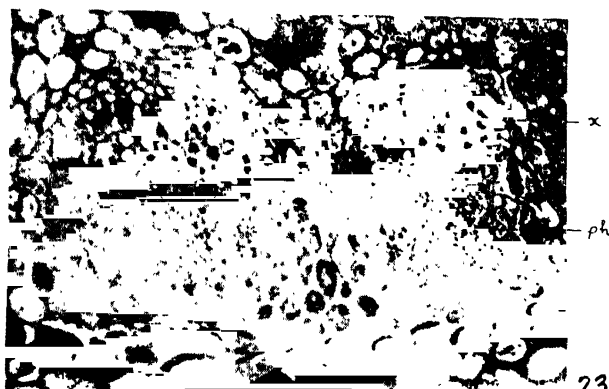
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EXPLANATION OF PLATES.

PLATE XXVI.

Ptilophyllum amarjolense.

- FIGS. 1, 1a-4. Detached petioles of *P. amarjolense*, Nos. 1 and 2 show the ventral surface and 1a shows the dorsal surface. ($\times 0.8$.)
- FIG. 5. A piece of rachis with detached pinnules. ($\times 0.8$.)
- FIG. 6. Epidermal cells on the dorsal surface of the pulvinus. ($\times 32.4$.)
- FIG. 7. Epidermal cells on the ventral surface of the pulvinus. ($\times 32.4$.)
- FIG. 8. Epidermal cells on the ventral surface of the petiole. ($\times 96.7$.)
- FIG. 9. Epidermal cells on the rachis. ($\times 32.4$.)
- FIG. 10. Transverse section at the base of a petiole. ($\times 15.5$.)
- FIG. 11. Part of transverse section of a petiole, showing two vascular bundles with xylem (x) and phloem (ph). ($\times 104.7$.)

PLATE XXVII.

Ptilophyllum amarjolense.

- FIGS. 12-16. Leaves of *P. amarjolense* showing variation in size and shape of pinnae. ($\times 0.8$.)
- FIG. 17. A single pinna, showing the upper epidermal cells. ($\times 15.5$.)
- FIG. 18. A single pinna, showing stomata packed in between the veins. ($\times 15.5$.)
- FIG. 19. A part of pinna, showing the orientation of the stomata. ($\times 44.5$.)
- FIG. 20. A part of pinna, showing the lower epidermal cells and stomata. ($\times 68.7$.)

PLATE XXVIII.

Ptilophyllum amarjolense.

- FIG. 21. Transverse section of rachis. ($\times 20.5$)
 FIG. 22. Part of transverse section of rachis, showing the inner row of vascular bundles arranged in a 'U' shaped fashion. ($\times 48.3$)
 FIG. 23. Part of transverse section of rachis, showing two vascular bundles with xylem (x) and phloem (ph). ($\times 81.3$)
 FIG. 24. Radial section of rachis, showing tracheids with scalariform pits. ($\times 27.2$)
 FIG. 25. Transverse section of a pinna. ($\times 15.5$)
 FIG. 26. Part of transverse section of a pinna, showing upper hypodermal cells (oh), palisade cells (lb), mesophyll (m), vascular bundle (vb), lower hypodermal cells (lh) and lower epidermal cells (le). ($\times 101.8$)

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THERMODYNAMICS OF SYSTEMS OF ANY NUMBER OF COMPONENTS

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1. INTRODUCTION.

Considerable progress in the development of a thermodynamic theory of liquids and solutions has been made during recent years by employing methods of statistical mechanics, but a solution has been obtained only under too restrictive assumptions of solutions being regular or strictly regular (Rushbrooke, 1949; Guggenheim, 1952). The theory assumes that in a liquid mixture molecules are arranged in a regular lattice, an assumption only appropriate to crystals and possibly to liquids only near their freezing-points. A new approach dispensing altogether with this lattice model has been made by Longuet-Higgins (1951) by assuming the solution to satisfy certain plausible conditions, but a wholly unrestricted statistical theory of solutions is beset with great difficulties and has yet to be fully worked out. In the meantime there has developed a large amount of experimental data on solutions which needs a quantitative discussion from theory. The purpose of the present paper is to develop a general thermodynamic theory of solutions for interpreting and correlating these data as best as possible, and in particular to find how the Clausius-Clapeyron relation requires modification in case of multicomponent systems. Treatments of binary systems have been given by several authors (Guggenheim, 1950; Ruhemann, 1939; Haselden, Newitt and Shah, 1951; R. Haase, 1950) and applications to a few cases also discussed. The case of multicomponent systems, however, seems not to have received sufficient attention.

2. EQUILIBRIUM CONDITIONS OF A MULTI-COMPONENT CONDENSED PHASE.

Our multi-component condensed phase is an open system, i.e., a system which can gain or lose matter as well as heat and work. The Gibbs function G , being an extensive property of the phase, depends on temperature T , pressure P and the amounts n_1, n_2, \dots (expressed in moles) of the various components of the system. Hence according to the laws of partial differentiation we have,

$$dG = \left(\frac{\partial G}{\partial T}\right)_{P, n_i} dT + \left(\frac{\partial G}{\partial P}\right)_{T, n_i} dP + \sum_{i=1}^{i=r} \left(\frac{\partial G}{\partial n_i}\right)_{T, P, n_j} dn_i, \quad \dots \quad (1)$$

where the index n_i denotes all the quantities of the type n_i except n_i itself. If we restrict ourselves to changes taking place in that phase without any alteration of the total amounts of each component, the system becomes a closed one as no matter is added to or removed from it during such changes. For such a closed system, we have from the laws of thermodynamics

$$dE + P dV = T dS, \quad \dots \quad (2)$$

and hence

$$dG = d(E + PV - TS) = -S dT + V dP. \quad \dots \quad (3)$$

Comparing (1) and (3)

$$\left(\frac{\partial G}{\partial T}\right)_{P, n_i} = -S, \left(\frac{\partial G}{\partial P}\right)_{T, n_i} = V. \quad \dots \quad \dots \quad \dots \quad (4)$$

Hence (1) becomes

$$dG = -S dT + V dP + \sum_{i=1}^{i=r} \mu_i dn_i, \quad \dots \quad \dots \quad \dots \quad (5)$$

where the chemical potential μ_i is given by

$$\mu_i = \left(\frac{\partial G}{\partial n_i}\right)_{T, P, n_j} \quad \dots \quad \dots \quad \dots \quad (6)$$

It follows from this definition of μ that it is an intensive property of the phase in question. In other words, μ is a function of T , P and the mole-fraction N_i , N_i being equal to $n_i/\Sigma n_i$. Any one of the components may be treated as a solvent and the remaining components expressed as mole-fractions N_i . Hence the number of independent variables N_i will be one less than the number of components. For the change in chemical potential of the component 1, we have for the most general variation,

$$d\mu_1 = \left(\frac{\partial \mu_1}{\partial T}\right)_{P, N} dT + \left(\frac{\partial \mu_1}{\partial P}\right)_{T, N} dP + \sum_{i=1}^{i=r-1} \left(\frac{\partial \mu_1}{\partial N_i}\right)_{T, P, N_j} dN_i \quad \dots \quad (7)$$

Using the well-known thermodynamical methods, equation (5) can be treated to yield

$$\begin{vmatrix} \frac{\partial T}{\partial x} & \frac{\partial T}{\partial y} \\ \frac{\partial S}{\partial x} & \frac{\partial S}{\partial y} \end{vmatrix} = \begin{vmatrix} \frac{\partial P}{\partial x} & \frac{\partial P}{\partial y} \\ \frac{\partial V}{\partial x} & \frac{\partial V}{\partial y} \end{vmatrix} + \begin{vmatrix} \frac{\partial n_1}{\partial x} & \frac{\partial n_1}{\partial y} \\ \frac{\partial \mu_1}{\partial x} & \frac{\partial \mu_1}{\partial y} \end{vmatrix} + \begin{vmatrix} \frac{\partial n_2}{\partial x} & \frac{\partial n_2}{\partial y} \\ \frac{\partial \mu_2}{\partial x} & \frac{\partial \mu_2}{\partial y} \end{vmatrix} + \dots$$

This immediately gives

$$\left(\frac{\partial \mu_i}{\partial T}\right)_{P, n_i, n_j} = -\left(\frac{\partial S_i}{\partial n_i}\right)_{T, P, n_j} = -\bar{S}_i \quad \dots \quad \dots \quad (8)$$

$$\left(\frac{\partial \mu_i}{\partial P}\right)_{T, n_i, n_j} = \left(\frac{\partial V}{\partial n_i}\right)_{T, P, n_j} = \bar{V}_i \quad \dots \quad \dots \quad (9)$$

where \bar{V}_i , \bar{S}_i respectively denote the increase in volume and entropy of the system due to unit increase in the number of moles of the type i , the pressure, temperature and the amounts of other components remaining unaltered. The change is assumed to be so small that the composition and nature of the system remain sensibly unaltered. The quantities \bar{V}_i and \bar{S}_i are respectively called partial molar volume and partial molar entropy of the components in the given phase. Further since μ depends on the mole-fractions and not on the total amount of components,

$$\left(\frac{\partial \mu_i}{\partial T}\right)_{P, n_i, n_j} = \left(\frac{\partial \mu_i}{\partial T}\right)_{P, N}; \quad \left(\frac{\partial \mu_i}{\partial P}\right)_{T, n_i, n_j} = \left(\frac{\partial \mu_i}{\partial P}\right)_{T, N}$$

Hence (7) yields

$$d\mu_1 = -\bar{S}_1 dT + \bar{V}_1 dP + \sum_{i=1}^{r-1} \left(\frac{\partial \mu_1}{\partial N_i} \right)_{T, P, N_j} dN_i \quad \dots \quad (10)$$

Similarly for the vapour phase,

$$d\mu_1' = -\bar{S}_1' dT + \bar{V}_1' dP + \sum_{i=1}^{r-1} \left(\frac{\partial \mu_1'}{\partial N_i'} \right)_{T, P, N_j'} dN_i' \quad \dots \quad (11)$$

Now from the well-known conditions of equilibrium of heterogeneous systems consisting of several components at a constant temperature T , and pressure P , we have for any component the relation,

$$\mu_i = \mu_i'.$$

Similarly for equilibrium at temperature $T+dT$ and pressure $P+dP$ we have

$$\mu_i + d\mu_i = \mu_i' + d\mu_i'.$$

Hence

$$d\mu_i = d\mu_i'.$$

Equations (10) and (11) then yield for the component 1,

$$\begin{aligned} -\bar{S}_1 dT + \bar{V}_1 dP + \sum_{i=1}^{r-1} \left(\frac{\partial \mu_1}{\partial N_i} \right)_{T, P, N} dN_i \\ = -\bar{S}_1' dT + \bar{V}_1' dP + \sum_{i=1}^{r-1} \left(\frac{\partial \mu_1'}{\partial N_i'} \right)_{T, P, N_j'} dN_i' \quad \dots \quad (12) \end{aligned}$$

For the component 2, we have

$$\begin{aligned} -\bar{S}_2 dT + \bar{V}_2 dP + \sum_{i=1}^{r-1} \left(\frac{\partial \mu_2}{\partial N_i} \right)_{T, P, N} dN_i \\ = -\bar{S}_2' dT + \bar{V}_2' dP + \sum_{i=1}^{r-1} \left(\frac{\partial \mu_2'}{\partial N_i'} \right)_{T, P, N_j'} dN_i' \quad \dots \quad (13) \end{aligned}$$

Similarly for the other components. Multiplying these equations by N_1, N_2, \dots, N_r respectively and adding we get

$$\begin{aligned} -\{N_1(\bar{S}_1' - \bar{S}_1) + N_2(\bar{S}_2' - \bar{S}_2) + \dots\} dT + \{N_1(\bar{V}_1' - \bar{V}_1) + N_2(\bar{V}_2' - \bar{V}_2) + \dots\} dP \\ = N_1 \left[\sum_{i=1}^{r-1} \left(\frac{\partial \mu_1}{\partial N_i} \right)_{T, P, N_j} dN_i - \sum_{i=1}^{r-1} \left(\frac{\partial \mu_1'}{\partial N_i'} \right)_{T, P, N_j'} dN_i' \right] \\ + N_2 \left[\sum_{i=1}^{r-1} \left(\frac{\partial \mu_2}{\partial N_i} \right)_{T, P, N_j} dN_i - \sum_{i=1}^{r-1} \left(\frac{\partial \mu_2'}{\partial N_i'} \right)_{T, P, N_j'} dN_i' \right] + \dots \text{to } r \text{ terms} \quad \dots \quad (14) \end{aligned}$$

Since the condensed phase was initially in equilibrium at the temperature T and pressure P and the mole-fractions N_1, N_2, \dots we have by applying the Gibbs-Duhem relation for changes at constant T and P

$$N_1 \sum_{i=1}^{r-1} \left(\frac{\partial \mu_1}{\partial N_i} \right)_{T, P, N_j} dN_i + N_2 \sum_{i=1}^{r-1} \left(\frac{\partial \mu_2}{\partial N_i} \right)_{T, P, N_j} dN_i + \dots = 0 \quad \dots \quad (15)$$

Further

$$N_1(\bar{S}_1' - \bar{S}_1) + N_2(\bar{S}_2' - \bar{S}_2) + \dots = \sum_{i=1}^r \frac{N_i L_i}{T} dT, \quad \dots \quad (16)$$

where $\sum N_i L_i$ is the heat of evaporation of N_1, N_2, \dots mole-fraction of the respective components simultaneously from the condensed phase, in other words, the heat of evaporation of one mole from the condensed phase, without altering its composition. From (8) L_i is the heat of evaporation of one mole of the component i without sensibly altering the composition of the solution.

As usual the volumes of the components in the condensed phase can be neglected in comparison to that of the vapour phase. Then equation (14), with the help of (15) and (16) yields

$$-\sum_{i=1}^r \frac{N_i L_i}{T} dT + \sum_{i=1}^r N_i \bar{V}_i' dP = - \left\{ N_1 \sum_{i=1}^{r-1} \left(\frac{\partial \mu_1'}{\partial N_i'} \right)_{T, P, N_j'} dN_i' + N_2 \sum_{i=1}^{r-1} \left(\frac{\partial \mu_2'}{\partial N_i'} \right)_{T, P, N_j'} dN_i' + \dots \text{up to } r \text{ terms} \right\} \dots \quad (17)$$

This is the general equation for a multi-component non-ideal system and refers to changes in T, P and N_i' . It may, however, be interesting to find how the variation of total pressure and temperature depends upon the concentrations in the condensed phase, rather than vapour phase.

Multiplying (12), (13) ... respectively by $N_1', N_2' \dots$ and adding we get,

$$- \{ N_1'(\bar{S}_1' - \bar{S}_1) + N_2'(\bar{S}_2' - \bar{S}_2) + \dots \} dT + \{ N_1'(\bar{V}_1' - \bar{V}_1) + N_2'(\bar{V}_2' - \bar{V}_2) + \dots \} dP \\ = - \left\{ N_1' \sum_{i=1}^{r-1} \left(\frac{\partial \mu_1'}{\partial N_i'} \right)_{T, P, N_j'} dN_i' - N_1' \sum_{i=1}^{r-1} \left(\frac{\partial \mu_1}{\partial N_i} \right)_{T, P, N_j} dN_i \right\} \\ - \left\{ N_2' \sum_{i=1}^{r-1} \left(\frac{\partial \mu_2'}{\partial N_i'} \right)_{T, P, N_j'} dN_i' - N_2' \sum_{i=1}^{r-1} \left(\frac{\partial \mu_2}{\partial N_i} \right)_{T, P, N_j} dN_i \right\} \\ + \dots \text{up to } r \text{ terms} \dots \quad (18)$$

But
$$\sum_{i=1}^r N_i'(\bar{S}_i' - \bar{S}_i) = \frac{\sum N_i' L_i^c}{T} = \frac{\sum N_i' L_i^c - L_M'}{T} \dots \quad (19)$$

where $L_M' = \sum N_i'(H_i - H_i^0)$ and L_i^c denotes the heat of condensation of one mole of i from the vapour into the solution without sensibly altering the composition of the solution.

Again Gibbs-Duhem relation for the vapour phase yields

$$N_1' \sum_{i=1}^{r-1} \left(\frac{\partial \mu_1'}{\partial N_i'} \right)_{T, P, N_j'} dN_i' + N_2' \sum_{i=1}^{r-1} \left(\frac{\partial \mu_2'}{\partial N_i'} \right)_{T, P, N_j'} dN_i' + \dots \text{up to } r \text{ terms} = 0 \quad \dots \quad (20)$$

Using (19) and (20) and neglecting the volume of the condensed phase in relation to the gaseous phase, equation (18) yields

$$-\frac{1}{T} \{ \sum N_i' L_i^c - \sum N_i'(H_i - H_i^0) \} dT + \sum N_i' \bar{V}_i' dP \\ = N_1' \sum_{i=1}^{r-1} \left(\frac{\partial \mu_1}{\partial N_i} \right)_{T, P, N_j} dN_i + N_2' \sum_{i=1}^{r-1} \left(\frac{\partial \mu_2}{\partial N_i} \right)_{T, P, N_j} dN_i + \dots \text{up to } r \text{ terms} \dots \quad (21)$$

The evaluation of the quantities, \bar{V}_i' , $(\partial\mu_i'/\partial N_i')_{T, P, N_j'}$, etc., for a non-ideal multi-component mixture is somewhat complicated and is often not required. A useful approximation is the particular case when the vapour pressures are not too high and the vapour phase can be treated as an ideal mixture, the condensed phase remaining non-ideal.

3. NON-IDEAL CONDENSED PHASE IN EQUILIBRIUM WITH IDEAL GASEOUS MIXTURE.

If the vapour phase is taken to be an ideal mixture of gases, we have,

$$N_1\bar{V}_1' + N_2\bar{V}_2' + \dots = \Sigma N_i RT/P. \quad \dots \quad (22)$$

Equation (17) with the help of (22) yields

$$\begin{aligned} - \sum_{i=1}^r \frac{N_i L_i}{T} dT + \sum_{i=1}^r N_i \frac{RT}{P} dP = - \left\{ N_1 \sum_{i=1}^{r-1} \left(\frac{\partial \mu_1'}{\partial N_i'} \right)_{T, P, N_j'} dN_i' \right. \\ \left. + N_2 \sum_{i=1}^{r-1} \left(\frac{\partial \mu_2'}{\partial N_i'} \right)_{T, P, N_j'} dN_i' + \dots \text{up to } r \text{ terms} \right\} \quad \dots \quad (23) \end{aligned}$$

Since the vapour phase is regarded as a mixture of perfect gases, we have for each component the chemical potential

$$\mu_i' = \mu_i^{\circ'} + RT \log p_i, \quad \dots \quad (24)$$

where $\mu_i^{\circ'}$ is a function of T and P alone and is independent of concentration. Hence

$$(\Delta \mu_i')_{T, P} = RT (\Delta \log p_i)_{T, P} = RT \Delta \log N_i' \quad \dots \quad (25)$$

since $p_i = PN_i'$.

Now, the right-hand side of equation (23) can be written down as

$$-N_1(\Delta \mu_1')_{T, P} - N_2(\Delta \mu_2')_{T, P} - \dots = - \sum_{i=1}^r N_i \cdot RT \Delta \log N_i'$$

from (25). Hence (23) yields

$$- \sum_{i=1}^r \frac{N_i L_i}{T} dT + \sum_{i=1}^r N_i \frac{RT}{P} dP = -RT \sum_{i=1}^r \frac{N_i}{N_i'} dN_i' \quad \dots \quad (26)$$

Now, we have to find $\Sigma N_i L_i$ in terms of the latent heat of evaporation L_i° of the pure components. Obviously the differential heat of dilution must be taken into account. We can imagine that we take a large (effectively infinite) quantity of the condensed phase in question and add to it N_1, N_2, \dots, N_r moles of the various components at constant temperature and pressure. Clearly the heat absorbed will be the differential heat of mixing N_1, N_2, \dots, N_r moles of the various components. If H_i is the partial molar heat content of the component i in the actual solution and H_i° the molar heat content of the pure component at the same temperature and pressure, then L_M the differential heat of mixing N_1, N_2, \dots, N_r

moles is clearly equal to $\sum_{i=1}^r N_i(H_i - H_i^{\circ})$. Since the solution is assumed to have more total heat than the individual pure components, the latent heat of evaporation of N_1, N_2, \dots, N_r moles of the components from the solution will evidently

be less than the latent heat of evaporation $\sum N_i L_i^\circ$ of the pure components by L_M . We have, therefore,

$$\sum_{i=1}^r N_i L_i = \sum_{i=1}^r N_i L_i^\circ - L_M.$$

Hence (26) yields, since $\sum N_i = 1$,

$$\frac{dP}{dT} = \frac{P}{RT^2} \left(\sum_{i=1}^r N_i L_i^\circ - L_M \right) - P \sum_{i=1}^r \frac{N_i}{N_i'} \frac{dN_i'}{dT}. \quad \dots \quad (27)$$

In the particular case of bi-component system, this becomes

$$\frac{1}{P} \frac{dP}{dT} = \frac{N_1 L_1^\circ + N_2 L_2^\circ - L_M}{RT^2} - \left(\frac{N_1}{N_1'} - \frac{N_2}{N_2'} \right) \frac{dN_1'}{dT}, \quad \dots \quad (28)$$

since $dN_1' + dN_2' = 0$ for a two-component system.

Equations (27) and (28) show how for a solution at given total pressure and given partial pressures of the components (N_1', N_2', \dots), the variation of total pressure with temperature depends on the concentration of the solution and the variation of partial pressure with temperature.

Similarly equation (21) yields for the case when the vapour phase is an ideal mixture,

$$\begin{aligned} & -\frac{1}{T} \{ \sum N_i' L_i^\circ - \sum N_i' (H_i - H_i^\circ) \} dT + \sum N_i' \frac{RT}{P} dP \\ & = N_1' \sum_{i=1}^{r-1} \left(\frac{\partial \mu_1}{\partial N_i} \right)_{T, P, N_j} dN_i + N_2' \sum_{i=1}^{r-1} \left(\frac{\partial \mu_2}{\partial N_i} \right)_{T, P, N_j} dN_i + \dots \text{up to } r \text{ terms} \dots \quad (29) \end{aligned}$$

Now, for every component of the condensed phase in equilibrium with the vapour phase, we have

$$\mu_1 = \mu_1'(T) + RT \log p_1,$$

where $\mu_1'(T)$ depends only on the temperature. Therefore

$$(\Delta \mu_1)_{T, P} = RT (\Delta \log p_1)_{T, P} = RT \sum_{i=1}^{r-1} \left(\frac{\partial \log p_1}{\partial N_i} \right)_{T, P, N_j} dN_i.$$

Hence (29) yields

$$\begin{aligned} & -\frac{1}{T} \left\{ \sum_{i=1}^r N_i' L_i^\circ - \sum_{i=1}^r N_i' (H_i - H_i^\circ) \right\} dT + \sum_{i=1}^r N_i' \frac{RT}{P} dP \\ & = RT \left[N_1' \sum_{i=1}^{r-1} \left(\frac{\partial \log p_1}{\partial N_i} \right)_{T, P, N_j} dN_i + N_2' \sum_{i=1}^{r-1} \left(\frac{\partial \log p_2}{\partial N_i} \right)_{T, P, N_j} dN_i \right. \\ & \quad \left. + \dots N_r' \sum_{i=1}^{r-1} \left(\frac{\partial \log p_r}{\partial N_i} \right)_{T, P, N_j} dN_i \right] \dots \quad (30) \end{aligned}$$

Now, the Duhem-Margules relation for the condensed phase gives

$$N_1 \sum_{i=1}^{r-1} \left(\frac{\partial \log p_1}{\partial N_i} \right)_{T, P, N_j} dN_i + \dots + N_r \sum_{i=1}^{r-1} \left(\frac{\partial \log p_r}{\partial N_i} \right)_{T, P, N_j} dN_i = 0 \dots \quad (31)$$

Combining (30) and (31), we obtain

$$\begin{aligned}
 & -\frac{1}{T} \left\{ \sum_{i=1}^r N_i' L_i^\circ - \sum_{i=1}^r N_i' (H_i - H_i^\circ) \right\} dT + \Sigma N_i' \frac{RT}{P} dP \\
 & = RT \left[\left(N_1' - \frac{N_1 N_r'}{N_r} \right) \sum_{i=1}^{r-1} \left(\frac{\partial \log p_1}{\partial N_i} \right)_{T, P, N_j} dN_i + \left(N_2' - \frac{N_2 N_r'}{N_r} \right) \right. \\
 & \quad \left. \sum_{i=1}^{r-1} \left(\frac{\partial \log p_2}{\partial N_i} \right)_{T, P, N_j} dN_i + \dots \text{up to } r \text{ terms} \right] \dots \dots (32)
 \end{aligned}$$

For a two-component system, $r = 2$, and equation (32) yields

$$\begin{aligned}
 & -\frac{1}{T} \left\{ N_1' L_1^\circ + N_2' L_2^\circ - N_1' (H_1 - H_1^\circ) - N_2' (H_2 - H_2^\circ) \right\} dT + \frac{RT}{P} dP \\
 & = RT \left(N_1' - \frac{N_1 N_2'}{N_2} \right) \left(\frac{\partial \log p_1}{\partial N_1} \right)_{T, P} dN_1. \dots \dots (33)
 \end{aligned}$$

In these formulae we have written N_1, N_2, N_1', N_2' simply to exhibit the symmetry of the expressions. Actually $N_2 = 1 - N_1$ and $N_2' = 1 - N_1'$. Equations (27) and (28) or (32) and (33) represent the general formulae giving the behaviour of non-ideal systems for all possible variations in the degrees of freedom of the system. If desired, the equations (27), (28), (32), (33) can be expressed in terms of the activity coefficients f_i by means of the relation $p_i = p_i^\circ N_i f_i = N_i' P$.

4. PARTICULAR CASES.

A. *Isothermal-isobaric changes.*

For such changes equations (27) and (32) yield

$$\sum_{i=1}^r \frac{N_i}{N_i'} dN_i' = 0 \dots \dots (34)$$

and

$$\begin{aligned}
 & \left(N_1' - \frac{N_1 N_r'}{N_r} \right) \sum_{i=1}^{r-1} \left(\frac{\partial \log p_1}{\partial N_i} \right)_{T, P, N_j} dN_i + \left(N_2' - \frac{N_2 N_r'}{N_r} \right) \\
 & \quad \sum_{i=1}^{r-1} \left(\frac{\partial \log p_2}{\partial N_i} \right)_{T, P, N_j} dN_i + \dots = 0 \dots \dots (35)
 \end{aligned}$$

both of which yield for a bi-component system $N_1/N_2 = N_1'/N_2'$, the condition for constant boiling mixture.

B. *Isobaric changes.*

Under these conditions, since $N_1' = p_1/P$, equation (28) yields

$$\left(\frac{dp_1}{dT} \right)_P = \frac{N_1 L_1^\circ + N_2 L_2^\circ - L_M}{RT^2} \left/ \left(\frac{N_1}{p_1} - \frac{N_2}{p_2} \right) \right. \dots \dots (36)$$

This gives the variation of partial pressure with temperature for any concentration of solution provided the total pressure remains constant. This can also be used to give the variation of partial pressure of one component with the boiling point for isobaric changes.

Equation (33) on the other hand yields for isobaric changes

$$\left(\frac{dN_1}{dT}\right)_P = -\frac{N_1'L_1^\circ + N_2'L_2^\circ - L_M'}{RT^2} \left/ \left(N_1' - \frac{N_1N_2'}{N_2}\right) \left(\frac{\partial \log p_1}{\partial N_1}\right)_{T,P} \right. \quad \dots \quad (37)$$

This shows that the variation of partial pressure of one component with the concentration of the solution at constant temperature and pressure is related to the variation of solubility of that component with temperature at constant pressure. Applied to boiling point, equation (37) gives the variation of the boiling point with concentration at constant pressure in terms of variation of partial pressure with concentration for isothermal-isobaric changes.

C. *Isothermal changes.*

For such changes equation (28) yields

$$\left(\frac{d \log P}{dN_1'}\right)_T = \left(\frac{N_2}{N_2'} - \frac{N_1}{N_1'}\right) \quad \dots \quad (38)$$

If for certain concentration of the solution, the right-hand side vanishes, the pressure will have a maximum or minimum value for that concentration of vapour. For such solutions $N_1/N_2 = N_1'/N_2'$, i.e., the composition in the liquid and vapour phases is identical and the liquid will vaporize unchanged like a pure substance. These are called constant boiling mixtures. Equation (33) on the other hand yields

$$\left(\frac{dP}{dN_1}\right)_T = \left(p_1 - \frac{N_1p_2}{N_2}\right) \left(\frac{d \log p_1}{dN_1}\right)_{T,P} \quad \dots \quad (39)$$

This equation gives a relation existing between the variation of total pressure with concentration at constant temperature and the variation of partial pressure with concentration at constant temperature and pressure. If the P versus N_1 curve shows a maxima or minima, $dP/dN_1 = 0$, and since $(d \log p_1/dN_1)_{T,P}$ is obviously not zero, we have the well-known condition of constant-boiling mixture.

Combining (38) and (39) we get

$$\left(\frac{dN_1'}{dN_1}\right)_T = \left(\frac{d \log p_1}{dN_1}\right)_{T,P} \frac{N_2'N_1'}{N_2} \quad \dots \quad (40)$$

D. *Changes at constant composition.*

For changes in which the composition of the vapour remains constant, equation (28) yields

$$\frac{1}{P} \left(\frac{dP}{dT}\right)_{N_1'} = \frac{N_1L_1^\circ + N_2L_2^\circ - L_M}{RT^2}, \quad \dots \quad (41)$$

while for changes at constant concentration of liquid, equation (33) yields

$$\frac{1}{P} \left(\frac{dP}{dT}\right)_{N_1} = \frac{N_1'L_1^\circ + N_2'L_2^\circ - L_M'}{RT^2} \quad \dots \quad (42)$$

5. CONDENSED PHASE AND VAPOUR PHASE BOTH BEING IDEAL MIXTURES.

It can be shown from statistical mechanics (Fowler and Guggenheim, 1952) that for ideal solutions of all concentrations, as well as for ideally dilute solutions of all concentrations, the (molar) chemical potentials μ of the various components in the liquid phase are given by

$$\mu_A = \mu_A^\circ + RT \log N_A, \quad \mu_B = \mu_B^\circ + RT \log N_B \quad \dots \quad (43)$$

where μ_A° and μ_B° are independent of the composition of the solution and N_A, N_B are the mole-fractions of the components A, B, \dots . In the case of ideal solutions μ_A° and μ_B° denote the chemical potentials of A and B for the pure liquids at the given temperature and pressure. In the case of ideally dilute solutions μ_A° can be taken to be the chemical potential for the pure solvent but μ_B° for the solute involves the interaction energy between solvent and solute molecules.

From equation (43) we obtain for the liquid phase

$$(d\mu_1)_{T,P} = RT d \log N_1.$$

Similarly for the gaseous phase we have

$$(d\mu_1')_{T,P} = RT d \log p_1.$$

Since for equilibrium $d\mu_1 = d\mu_1'$, we get

$$\frac{d \log p_1}{dN_1} = \frac{d \log N_1}{dN_1} = \frac{1}{N_1} \quad \dots \quad (44)$$

for a bi-component system.

The result may be substituted in (33) and yields

$$-\frac{N_1' L_1^\circ + N_2' L_2^\circ}{T} dT + \frac{RT}{P} dP = RT \left(\frac{N_1'}{N_1} - \frac{N_2'}{N_2} \right) dN_1 \dots \quad (45)$$

since $L_M' = 0$ for ideal mixtures.

As shown by Fowler and Guggenheim, equation (43) yields the laws of Henry and Raoult, viz.,

$$p_s = k_s N_s, \quad p_0 = p_0^\circ N_0,$$

where p_s, p_0 denote respectively the partial pressures of the solute and the solvent, p_0° is the vapour pressure of pure solvent, and k_s is a constant depending upon pressure, temperature and the nature of the solute. Assuming both the components to be liquids and applying Raoult's law and Clausius-Clapeyron equation to both the components, equation (45) can be shown to yield

$$\frac{1}{P} \frac{dP}{dT} = \frac{N_1 L_1^\circ + N_2 L_2^\circ}{RT^2} - \left(\frac{N_1'}{N_1} - \frac{N_2'}{N_2} \right) \frac{dN_1'}{dT}, \quad \dots \quad (46)$$

in agreement with (28). Thus (28) and (33) become identical in the case of ideal mixtures.

For changes at constant pressure equation (46) yields

$$\left(\frac{dN_1}{dT} \right)_P = - \frac{N_1' L_1^\circ + N_2' L_2^\circ}{RT^2} / \left(\frac{N_1'}{N_1} - \frac{N_2'}{N_2} \right). \quad \dots \quad (47)$$

If the component 2 (solute) is considered non-volatile, $N_2' = 0$ and (47) becomes

$$\left(\frac{dN_1}{dT}\right)_P = -\frac{N_1 L_1^\circ}{RT^2} \quad \dots \quad (48)$$

Integrating and considering the change in temperature to be very small we obtain approximately,

$$\log \frac{1}{N_1} = \frac{L_1^\circ}{RT^2} \Delta T, \quad \dots \quad (49)$$

a formula attributed to van't Hoff giving the change in boiling-point with concentration.

For changes at constant temperature (39) yields

$$\left(\frac{dP}{dN_1}\right)_T = \left(p_1 - \frac{p_2 N_1}{N_2}\right) \frac{1}{N_1} \simeq \frac{p_1}{N_1}, \quad \dots \quad (50)$$

if the solute 2 is non-volatile. For small changes in concentration this yields

$$(p_1^\circ - p_1)/p_1^\circ = N_2,$$

a law due to van't Hoff giving the lowering of vapour pressure with concentration of the solute.

We have stated above the various formulae for non-ideal and ideal solutions of any concentration at varying conditions of temperature, pressure and concentration. The detailed experimental test of these formulae is taken up in a subsequent paper.

It is a great pleasure to thank Professor A. C. Chatterji for drawing our attention to this problem, and his keen interest in the work.

SUMMARY.

In this paper a generalized thermodynamic theory of multicomponent systems based on Gibbs' method has been developed and the general conditions of equilibrium for a mixture of chemically non-interacting constituents existing in both the condensed and vapour phases worked out. The temperature, pressure and mole-fractions of the various components have all been allowed to vary simultaneously and a general equation connecting all these variations obtained for any solution of non-electrolytes, giving the modified Clausius-Clapeyron relation. From this equation various important formulae for particular cases have been deduced, all of which are capable of experimental verification. For ideal mixtures the relations become particularly simple and readily yield the well-known laws of changes in temperature and pressure with concentration.

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OCURRENCE OF SPARGANIUM IN THE DECCAN INTERTRAPPEANS OF MADHYA PRADESH, INDIA

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INTRODUCTION.

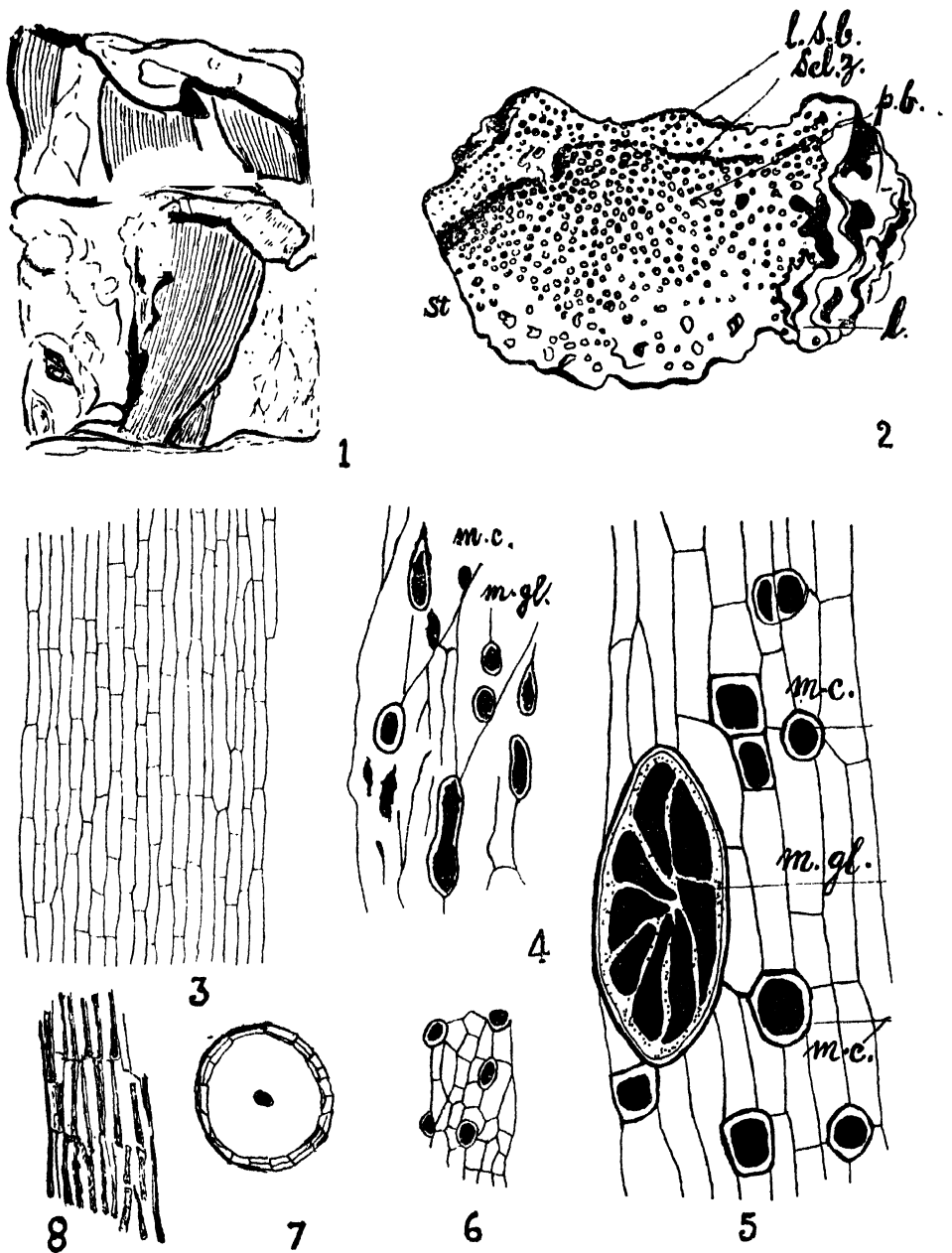
Sparganium is the sole genus of the family Sparganiaceae believed to be variously allied to Pandanaceae, Typhaceae and Xanthorrhaceae (Bentham and Hooker, 1883, 3, 955; Engler, 1887 in Engler and Prantl, 1887, 2 (1), 192-193; Graebner, 1900, 1-26; Rendle, 1904, 1, 191-193; Hutchinson, 1934, 2, 125). *Index Kewensis* (II, 1895) and Supplements to it, 1-10, (1886-1940) enlist about 80 species out of which 15-20 are well known. About 17 species are known in the fossils (Graebner, 1900, 193; Jongmans, 1913, 489; Berry, 1924, 342-348). Many of the living species are the inhabitants of the Northern Temperate regions in Europe, especially the Scandinavian countries from which more than 15 living species are known: 11 are known from North America and 2 from North Africa. Others are reported from Central Asia, Himalayas, China, Japan, Sakhalin Islands, Korea, Australia and New Zealand. Evidently the genus has quite a wide geographical distribution in the Northern Hemisphere today; and also in the past, as many of the fossil species are reported from the North Temperate regions of Europe and America. The genus is absent today in South America, South Africa and Peninsular India. Most of the fossil species with the exception of *Sparganium cretaceum* Heer from the Cretaceous of Greenland, belong to the Tertiary period ranging from Eocene to Pleistocene, mostly to Miocene.

In India two living species are found in the Himalayas, in Kashmir, Sikkim and Khasi Hills (Hooker, 1894, 6, 489-490): and some impressions resembling them or perhaps *Typha* have been reported from the Pleistocene beds of Kashmir, the Karewas (Puri, 1946, 169).

Most of the fossil species are known from the impressions of leaves, inflorescence, and fruits, but the material on which the present work is based is partly silicified and partly impressed. It was collected at the well-known Tertiary fossils' locality discovered by Dr. K. P. Rode at Mohgaon Kalan in the District Chhindwara in Madhya Pradesh and also at Sausar, Rama Kona, and other places near Nagpur where the genus abounds in light brown, yellow or dark green chertified rocks. Some excellent hand specimens were collected at these places on two trips in 1940 and later and formed the basis on which the present investigations were made.

OBSERVATIONS.

The genus is represented by numerous impressions and petrifications of leaves with long parallel, upraised veins (Pl. XXIX, figs. 21 and 24, and Figs. 1 and 3) with short cross connections, the lateral veins or the nervilles, which form an extremely fine and regular network of small square or oblong cubicles (Fig. 3), very characteristic of the leaves of the modern species of the genus, like *S. ramosum* or *S. simplex* (Pl. XXIX, figs. 20 and 26). But since such veins are comparable with those of many other plants like *Orchidantha longifolia*, *Semele androgyna*, *Iris versicolor*, species of *Gladiolus*, *Valisneria spiralis*, etc., their real identity was confirmed only after their internal structure was studied and many mucilage glands, 'Schleimdrüsen' (Figs. 4



FIGS. 1-8. *Sparganium* in the Deccan Intertappeans.

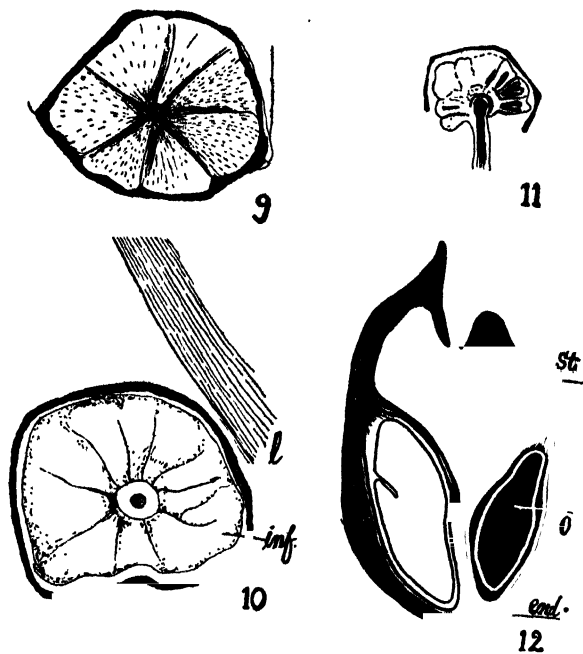
Fig. 1. Part of a block of yellowish chert, 17×8.5 cm., showing numerous leaf impressions, some of which are shown here. $\times 1$. Fig. 2. T.S. of stem, *st*, enclosed by leaf sheaths: *l*—leaf; *l.s.b.*—leaf-sheath bundle; *scl.z.*—zone of sclerenchyma; *p.b.*—pith bundle. $\times 2$. Fig. 3. Venation of the fossil leaf. $\times 82$ approx. Fig. 4. Mucilage glands and myriophyll cells, *m.gl.* and *m.c.*, in the fossil leaf. $\times 128$. Fig. 5. The same in the leaf of living *Sparganium simplex* Huds. $\times 215$. Fig. 6. Myriophyll cells in the bract of a fossil fruit. $\times 14$. Fig. 7. A flabby tertiary root (T.S.). $\times 82$: Note the large hollow cavity. Fig. 8. Surface view of the cells of the flabby tertiary root of the fossil. $\times 82$.

and 6, and Fig. 25, *m.gl.*) and myriophyllin cells, 'Myriophyllinzellen' (Fig. 6, *m.c.* and Fig. 25, *m.c.*) having structure similar to those described in the living species (Figs. 20 and 26, and Fig. 5) by Solereder and Meyer (1933), were found in the fossil material (cf. Figs. 25 and 26, and Figs. 4 and 5). They showed the same details of arrangement as are found in the leaves of living material. The mesophyll in the genus *Sparganium* as in *Iris* is arranged in series alternating with air canals between two long upraised veins and this was also found in the fossil leaves (Figs. 19 and 21, and Fig. 1). The leaves in the fossil species, therefore, must have been erect or semi-erect as they are today in *Sparganium ecetum* or *S. simplex*. Presumably the plants were half submerged and half emerged from the shallow waters of ponds in which they were growing like the sword-shaped leaves of *Alpinia galanga* which also grows on moist banks of rivers or in shallow ponds. Some of the early leaves on the plants might have been thin and submerged as those shown in Fig. 24, but the great majority of them must have been erect or a little slanting, their wide leaf bases extending into sheaths to embrace each other. In shape they appear to have been linear lanceolate (Fig. 1 and Figs. 21 and 24). They measure 12–25 mm. in width but their exact length is difficult to determine as whole specimens are not obtainable. But it must have been considerable, more than a meter in erect leaves. In most of the specimens the veins running parallel stand out quite conspicuously, especially in casts (Fig. 21). The size of the meshes varies from the base towards apex, the larger quadrangular or oblong meshes being towards the sheathing base and smaller ones towards the apex of the leaf.

Associated with some of the leaf impressions and petrifications were found pieces of stem ensheathed by the leaf-bases (Fig. 2 and Fig. 19). The axis enclosed by the leaf sheaths was oval or triangular and completely ensheathed as it is in the living species like *S. ramosum* or *S. erectum* (Fig. 19, *st.l₁,l₂*). The structure of the enclosed axis is broadly similar to that of *Sparganium* and *Typha* (Fig. 2). There is a distinct inner and outer cortex in which circular or semi-circular, juxtapositioned vascular bundles are spread below hypodermis. There are also numerous bundles in the central pith as in the living material. The shape of the vascular bundles depends upon their position in the axis. The bundles are collateral and closed. They have a ventral cap of semilunar sclerenchyma except in those bundles which lie immediately below the epidermis. These have circular or bilenticular rings of sclerenchyma. Many small fibre bundles and a few fibro-vascular bundles occur in the hypoderm separating the lacunar cortex from the central pith by a discontinuous ring of sclerenchyma (Fig. 2, *scl.z.*). A detailed study of the stem characters and the vascular bundles has been made and will be dealt with later separately.

Besides leaves and the axis enclosed by them the species is represented by bits of fruiting axes and fruits which sometimes occur as moulds and sometimes as petrifications (Figs. 9–11 and Fig. 18). Figs. 9 and 10 show diagrammatically two moulds found in a hand specimen of dark green olivaceous chert (Fig. 18) out of the five cavities, indicated on it by arrows. There are two more but rather indistinct. In the fifth one there is a clear extension of the floral axis, which must have been passing through it (Fig. 11), as it does in the living plant (Fig. 13).

The inflorescence in *Sparganium* is unisexual and consists of a sessile capitulum (Fig. 13, *Cap.*). The drupes are borne on it radially around a central, subglobose head (Fig. 13). In the block of chert in which the above mentioned moulds of infructescence occur, there is a fifth one which is deep seated. It is partly silicified but as this block is made up of dark green olivaceous chert, it is difficult to make out its whole structure. It is in oblique fracture. Presumably it represents a tertiary branch borne on a lateral shoot of infructescence (cf. Figs. 11 and 13). In the mould shown in Fig. 10 there are two rings in the centre left by the central head around which the impressions of 10 drupes are seen. There is also a leaf by its side

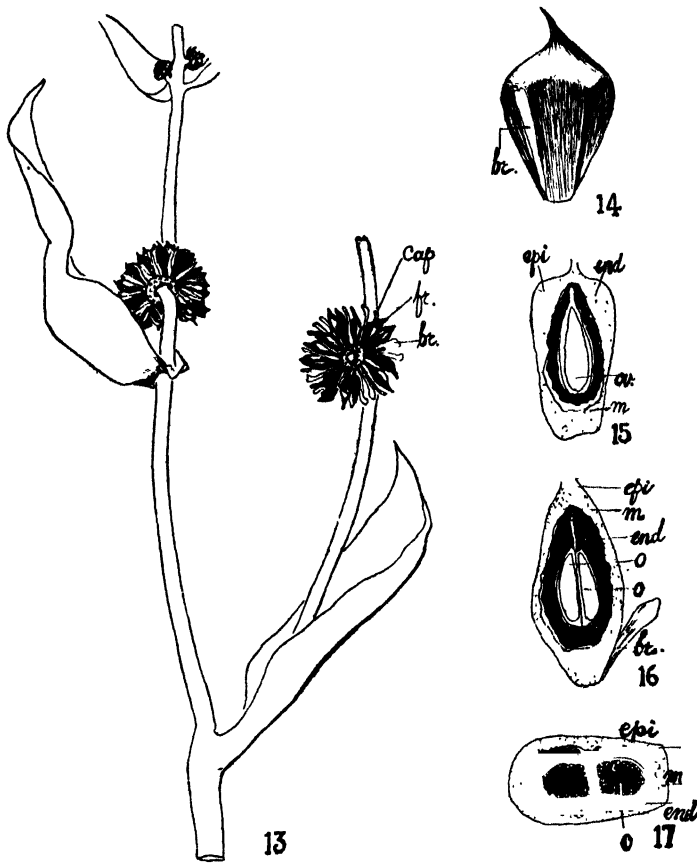


FIGS. 9-12. *Sparganium* in the Deccan Intertrappeans.

Figs. 9 and 10. Two moulds formed by the infructescence, *inf.*, in an olive green chert shown in Plate I, fig. 18. *l*—leaf impression. Note the ring of the capitulum in Fig. 10 on which the fruits were lodged. $\times 2$. Fig. 11. A third infructescence fractured in longitudinally in the same chert. $\times 2$. Fig. 12. Two fossil fruits cut sidewise showing styles, *st*, and seeds, *o*, with endocarp *end.* $\times 14$.

(Fig. 10, 1). In Fig. 9 there are impressions of only 7. In the longitudinally fractured capitulum shown in Fig. 11 some eight drupes are seen two of which appear to have two carpels. Very probably the fossil species had two confluent carpels as in living species like *S. eurycarpum*, *S. borderei* or *S. polyedrum*. The bicarpellate nature of the drupes is very clearly brought out by the transverse section of a fossil fruit (Fig. 22) from which a peel preparation was made by Dr. K. R. Surange of Lucknow and is shown here (Fig. 22). However, it should be remembered here that even in the so-called habitually bicarpellate species of *Sparganium* like *S. eurycarpum*, *S. androcladum* or *S. polyedrum*, one does come across monocarpic drupes (Figs. 14-17). In the cherts obtainable at Mohgaon Kalan, Sausar and other places one always notices small diamond-shaped, single or double cavities left by the obpyramidal fruits that must have been detached from the capitula and floated over to some another place by water. The fruits of the fossil species appear to be conical, regularly angled, 2.2-5 mm. in length and about 2.2 mm. in diameter in their broadest part (Figs. 22-23). The epicarp in the fruits of *Sparganium* is thin and mesocarp spongy and areolated (Figs. 14-17). These are not preserved but the endocarp which is stony is well preserved (Fig. 12 and Figs. 22 and 23). The drupes in a capitulum are always mixed with bracts and perianth leaves (Figs. 13, 14, 16, *br.*), and they are well preserved. They also have myriophyllin cells as in living material (Fig. 6). In fact these cells and mucilage glands are a distinctive feature of all parts of *Sparganium*.

In the midst of some of the leaves and bits of stem, numerous secondary and tertiary roots are also preserved and their structure is nearly the same as that of



FIGS. 13-17. *Sparganium eurycarpum* Engelm.

Fig. 13. A part of a large inflorescence showing fruits formed in heads, *cap.*, on tertiary axes. *fr.*—fruit; *br.*—bract. $\times \frac{3}{4}$. Figs. 14-17. Fruits of the same: *br.*—bract; *epi.*—epicarp; *m.*—mesocarp; *end.*—endocarp; *o.*—seed. Fig. 15. L.S. of a monocarpic drupe. $\times 4.5$. Fig. 16. L.S. of another fruit of the same plant having two carpels. Fig. 17. T.S. of a bicarpellary fruit of the same plant. $\times 4.5$.

the roots of *S. ramosum* or *S. eurycarpum*, if not identical with it (Figs. 7 and 8). These tertiary roots are flabby, aerolating organs and are hollow. They arise on large secondary roots which resemble in certain respects the roots of *Typha angustifolia*.

CONCLUSION.

When all these details of the structure of the leaf, axis, inflorescence, fruits, and roots are taken into account, along with the constant association of mucilage glands and myriophyllum cells, one is left in no doubt as to the identity of the plant with the genus *Sparganium*, every part of which is abundantly represented in cherts. From the preliminary observations made on the material collected at different places, it seems to me, that probably more than one species existed there: one large, more or less erect and the other small and more or less fluviatile. This is quite possible, because, *Sparganium* thrives in shallow ponds and in slow moving streams. Very often one or two species grow in a locality, each one dominating the whole

aspect of vegetation in certain places. For example, the shallow ponds at Bramhope and other places near Leeds or those at Hagley near Oxford are largely dominated by *S. erectum* (vide Tansley, 1939, pp. 285, 626, etc.). In view of these facts, it would be hazardous to name the Indian species without critically examining all the available material and sorting it out into relevant parts. Hence no specific name or names are proposed at this juncture. It is also likely that some of the earlier material referred to other form genera will eventually have to be transferred to this genus. Further work along these lines is in progress.

SUMMARY.

The paper gives an account of the occurrence of the genus *Sparganium* in the Deccan Intertrappean Series of Nagpur, all parts of which are available in cherts. Possibly there were more than one species growing in the area, the material of which has been collected from different localities and is being examined critically. *Sparganium* is essentially a Tertiary genus (Seward, 1931, 451) confirming the age of that series to be Tertiary.

ACKNOWLEDGEMENTS.

In the end, I have to thank Professor S. P. Agharkar for his help and advice and Professor T. M. Harris, of the University of Reading, Dr. A. Allsopp, University of Manchester, Professor T. G. Tutin, University of Leicester, authorities of the Kew Herbarium, Kew, and of the Dudley Herbarium of the University of Stanford, California, for sending me some excellent specimens of the species of *Sparganium* which greatly facilitated the identification of the plant. My thanks are also due to Dr. K. R. Surange for the peel preparation he made and to Professor V. V. Apte, Fergusson College, Poona, for the loan of some literature.

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EXPLANATION OF PLATE FIGURES

- Figs. 18-26. Illustrating Dr. T. S. Mahabalé's paper on *Sparganium* in the Deccan intertrappeans, M. P. India.
 Fig. 18. A chert with 5 moulds of capitula and leaf impressions. $\times \frac{1}{4}$.
 „ 19. T.S. of petrified stem, st. ensheathed by leaves, l_1, l_2 . $\times 55$.
 „ 20. A part of the leaf of *S. simplex* showing mucilage glands, *m.gl.*, and myriophyllin cells, *m.c.* in surface view. $\times 75$.
 21. Cast of a leaf showing conspicuously upraised, parallel veins. N.S.
 „ 22. Peel transfer of a fruit section showing two carpels and endocarp with remnants of mesocarp adhering to docarp. $\times 55$. (From a peel preparation made by Dr. K. R. Surange.)



Figs. 18-26. *Sparganium* in the Deccan Intertrappeans.

- Fig. 23. V.S. of fossil fruit showing styles and two seeds in lateral view. The thick dark outline is of the endocarp. $\times 55$. Note the adjacent fruit also cut in part.
- „ 24. Surface view of a leaf, possibly of a fluviatile species showing slender veins and cross connections. N.S.
- „ 25. Portion of a fossil leaf showing mucilage glands, *m.gl.* and myriophyllin cells, *m.c.* $\times 38$ approx.
- „ 26. Surface view of a part of leaf of *S. eurycarpum* mounted entire to show parallel veins, their cross connections, mucilage glands and numerous myriophyllin cells. $\times 38$ approx.

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SOME OBSERVATIONS ON THE EFFECT OF LIGHT ON 'SILENT' ELECTRICAL DISCHARGE THROUGH IODINE VAPOUR

by S. R. KHASTGIR F.N.I., and P. S. V. SETTY, Banaras Hindu University.

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1. INTRODUCTION.

In the oscillograms taken with iodine vapour under 'silent' electrical discharge in an ozonizer, we have already shown (Khastgir and Setty, 1952) that there are two types of pulses which are distinct in intensity, position and distribution. By considering Loeb and Meek's streamer theory (Loeb and Meek, 1941), as applied to 'silent' discharges, it has also been shown (Khastgir and Srivastava, 1953) that the insulating material (glass wall) intervening the gas or vapour and the electrodes introduces certain features which provide a fundamental basis for the occurrences of the two distinct types of pulses in such discharges. The two types of pulses were also reported earlier by Deb and Ghosh (1948) in air and oxygen. What we have called the '*discharge*' pulses, previously identified by Deb and Ghosh, as 'high frequency' pulses, are considered as due to the discharge or discharges between the negative charge on the intervening glass surface and an array of positive ions closed to it in the manner suggested by Mitra (Deb and Ghosh, 1946, 1948). The formation of the electrical double layer on and near the glass surface has been regarded as a consequence of the streamer mechanism of Loeb and Meek, even when the quantitative criterion for streamer formation does not prevail. (Khastgir and Setty, 1953.) What we have called the *Townsend Pulses*, on the other hand, are considered as flashes across a *gap* (that is produced between the stationary array of positive ions and the conducting column reaching the opposite electrode) when it gets bridged up under suitable conditions. These pulses may be identified with the 'low frequency' pulses of Deb and Ghosh.

The object of the present paper is to describe some experimental results with iodine vapour, at saturation vapour pressure inside a discharge tube fitted with external 'sleeve'-electrodes and excited by varying voltages of 50 cycles/sec., showing the two distinct types of pulses and confirming the view regarding the origin of the 'discharge' pulses. We shall also furnish oscillographic evidence regarding the nature of the two types of pulses suggesting strongly that they are of distinctly different origin. Along with these oscillographic observations, an account will also be given in the paper of parallel sets of experimental results on Joshi Effect observed by directly measuring the discharge current and also by detecting in a radio receiver the R.F. oscillations as modulated by the pulses in the A.C. 'silent' discharge.

2. EXPERIMENTAL DETAILS AND PROCEDURE.

(a) Discharge tube and its excitation.

The details of the iodine vapour discharge tube are as follows:

Length ..	15 cms.
Sectional diameter ..	1.8 cms.
Pressure ..	3 mm. (Temperature = 40°C.).

The discharge tube was fitted up with two external 'sleeve'-electrodes. Each sleeve'-electrode consisted of a few turns of copper wire wound round the tube and

each electrode was usually at a distance of 3.4 cms. from either end of the discharge tube. The distance between the 'sleeve'-electrodes could be adjusted to have any desired value.

The discharge tube was excited by varying voltages of 50 cycles/sec. For this purpose, the D.C. line voltage of 220 volts was converted into A.C. 110 volts (50 cycles/sec.) by a suitable rotary converter and with the help of a potentiometric device and a step-up transformer, a range of voltage, 0-3,000 volts, of 50 cycles/sec. was obtained. The voltage in the primary was read off from an A.C. voltmeter and from a knowledge of the transformation ratio of the step-up transformer, the secondary voltage applied to the electrodes of the discharge tube was estimated.

(b) Method of Irradiation.

For irradiating the discharge tube, usually a 200 watt electric light enclosed in a wooden box was employed with the provision of a suitable opening and a shutter. The discharge tube was suspended with its length horizontal, so that a flood of light could be made to fall uniformly on the entire length of the discharge tube. Special precaution was taken to prevent any scattered or reflected light from falling on any part of the discharge tube. Observations of the light effect were made with the electric light switched on, but with the shutter off and on as required.

(c) Oscillographic method.

For the purpose of observing and photographing the pulses in the A.C. 'silent' discharge, a suitable high resistance (variable) was inserted in series with the discharge tube. When the discharge tube was excited by a suitable voltage of 50 cycles/sec., the voltage developed across the high resistance was applied to the *y*-plates of an oscillograph and the linear time base voltage was given to the *x*-plates. The voltage developed across the high resistance was usually amplified to a suitable extent by the amplifier in the oscillograph unit and the oscillogram obtained was properly synchronized and photographed, when desired, by a F/1.5 camera. The sweep-frequency of the linear time base was usually set at the value which corresponded to 50 milli-seconds for which the pulses appeared as straight lines. Suitable higher sweep-frequencies were employed for studying the nature of the pulses.

In Fig. 1 are shown the circuit connections for the oscillographic observations with a discharge tube under 'silent' electrical discharge.

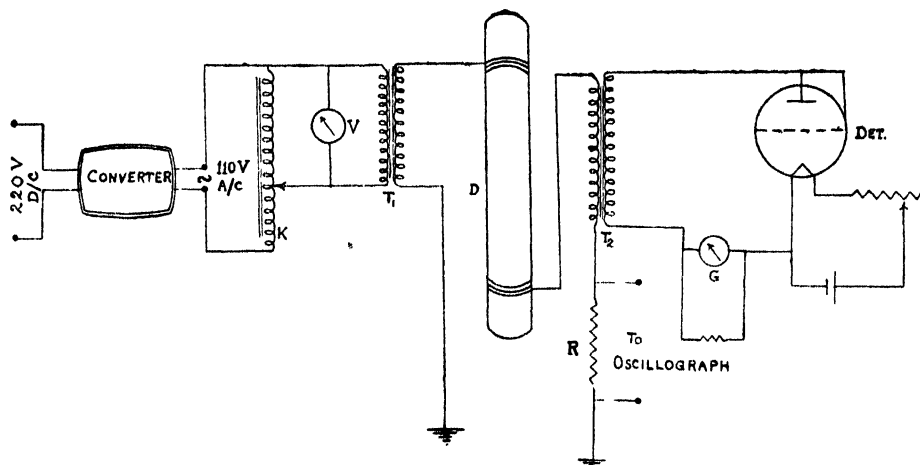


FIG. 1. D, discharge tube; K, 'Variac'; V, Voltmeter; T₁, High-tension A.T. transformer; T₂, A.F. transformer. DET, detector valve; G, galvanometer.

(d) *Method of measuring the discharge current.*

A suitable valve-detector (or a germanium crystal detector) was employed as an indicator of the discharge current. The detector unit was placed across the secondary of a suitable A.F. transformer, the primary of which was in the actual discharge circuit. In the secondary circuit, a suitably shunted mirror galvanometer was placed in series with the detector. The galvanometer indicated the rectified current and the detector unit was carefully calibrated. For a range of small input voltage giving galvanometer deflection of the same order of magnitude as observed in the measurement of the discharge current, the rectified current was found to be nearly proportional to the input A.C. voltage. Since the input voltage across the secondary due to the discharge current in the primary circuit can be taken proportional to the discharge current itself, the galvanometer deflection due to the rectified current should also be nearly proportional to the discharge current. The actual value of the discharge current could be easily obtained.

The circuit connections for the measurement of the discharge current with the detector unit are also shown in Fig. 1.

(e) *Experimental arrangements in Receiver Experiments for the study of modulated R.F. oscillations in the A.C. 'silent' discharge.*

In these receiver experiments, a long vertical copper wire connected to a coil wound round the discharge tube at some suitable position between the two external 'sleeve'-electrodes was used as a radiating antenna for the R.F. oscillations produced in the discharge tube. A T.R.F. receiver or a receiver of the superhet type worked with a receiving *T*-aerial was employed to detect the R.F. oscillations. The same mirror galvanometer as was used in the detector circuit for the measurement of the discharge current was placed in the anode circuit of the detector valve of the receiver and the no-signal anode current was balanced out in the usual way. With the reception of the R.F. oscillations, the rectified output current in the detector valve of the receiver produced a deflection in the galvanometer which was tuned by the variable condenser of the radio receiver. A loudspeaker at the output end after the A.F. amplification was also used for getting the aural response. The R.F. oscillations modulated by the pulses in the A.C. 'silent' discharge when received and tuned in this manner produced a sound in the loudspeaker. The tuned deflection of the galvanometer in the anode circuit of the detector valve of the receiver showed an increase or decrease on irradiation, according to conditions favourable for the production of positive or negative Joshi Effect. A corresponding increase or decrease of sound in the loudspeaker was also heard according to the nature of the light effect. The receiver could be tuned to one or another of the several discrete frequencies of the R.F. oscillations in the A.C. 'silent' discharge.

3. OSCILLOGRAMS OF THE TWO TYPES OF PULSES IN A.C. 'SILENT' DISCHARGE IN IODINE VAPOUR.

(a) *Oscillograms for different applied voltages.*

The C.R.O. patterns obtained with iodine vapour in a discharge tube fitted with external 'sleeve'-electrodes, when each electrode was at some distance from either end of the discharge tube, showed the following features:

- (i) At about 550 volts the oscillogram in dark showed only the 50 cycles/sec. current trace. On irradiation certain discrete pulses, one on each peak, appeared as lines (with low sweep-frequency). These are considered as the *Townsend pulses*.
- (ii) At a slightly higher voltage (700 V) the oscillograms in dark showed some longer pulses near the current peaks along with the shorter

Townsend pulses in slightly different positions. These longer pulses are regarded as the 'discharge' pulses. On irradiation the 'discharge' pulses were quenched completely or reduced considerably but the shorter Townsend pulses persisted.

- (iii) At higher voltages, the oscillograms in dark showed more 'discharge' pulses along with the Townsend pulses. On irradiation, the former were reduced in length and the latter were found to increase in number.
- (iv) At still higher voltages, the oscillograms in the dark showed only a few 'discharge' pulses but more Townsend pulses. On irradiation, the few 'discharge' pulses were either completely quenched or reduced, and the Townsend pulses increased in number and sometimes in length.
- (v) At very high voltage (2,500 V) the 'discharge' pulses were not usually observed. All the pulses were Townsend pulses, the oscillograms in dark and light being practically identical.

The following characteristics of the pulses observed with the iodine vapour 'sleeve'-discharge tube are to be noted:

- (a) Existence of a critical voltage (which is identified with the 'threshold' potential) for the Townsend pulses to occur in dark.
- (b) Initiation of the Townsend pulses by light at voltage slightly less than the 'threshold' potential.
- (c) Existence of a critical voltage (which is somewhat higher than the 'threshold' potential) for the 'discharge' pulses to occur.
- (d) Difference in intensity, position and distribution of the two types of pulses.
- (e) Complete quenching or reduction of the 'discharge' pulses on irradiation.
- (f) Disappearance of the 'discharge' pulses at some high applied voltage.

The 'threshold potential' and the initiation of Townsend pulses by light at voltage slightly less than the 'threshold' value have been explained elsewhere (Khastgir and Srivastava, 1953) by considering the streamer theory of Loeb and Meek as applied to A.C. 'silent' discharges. Since 'discharge' pulses have been attributed to discharge or discharges and neutralization of the opposite charges in the electrical double layer on and near the intervening glass surface, it is evident that there should be pulses on this account at a certain value of the applied voltage when the density of charge in the electrical double layer attains a requisite value. This is exactly what has been observed in our experiments. According to this view regarding the origin of the 'discharge' pulses, it is also expected that in a discharge tube with external 'sleeve'-electrodes, where each electrode is at some distance from either end of the discharge tube, the 'discharge' pulses should disappear at some high value of the applied voltage, since at such high voltage, the electrons have sufficiently high velocities, so that some of them overshoot the electrodes and cause thereby an inadequate density of charge on the glass surface (opposite to either electrode) for the 'discharge' pulses to occur. This is also substantiated by our experimental results.

In Fig. 2 are shown oscillograms for three different voltages: (a) 540 volts, (b) 1,100 volts, and (c) 2,000 volts of 50 cycles per second, the distance between the 'sleeve'-electrodes of the discharge tube being 8.5 cms. It can be seen from the oscillograms for 540 volts that the Townsend pulses were initiated by the incidence of light, there being no such pulses at this voltage in the absence of light. This showed that there was positive Joshi Effect in iodine vapour at voltage slightly less than the 'threshold' potential. It is clear from the oscillograms for 1,100 volts that there appeared 'discharge' pulses in the dark along with the Townsend pulses and that these 'discharge' pulses were quenched on irradiation. The oscillograms

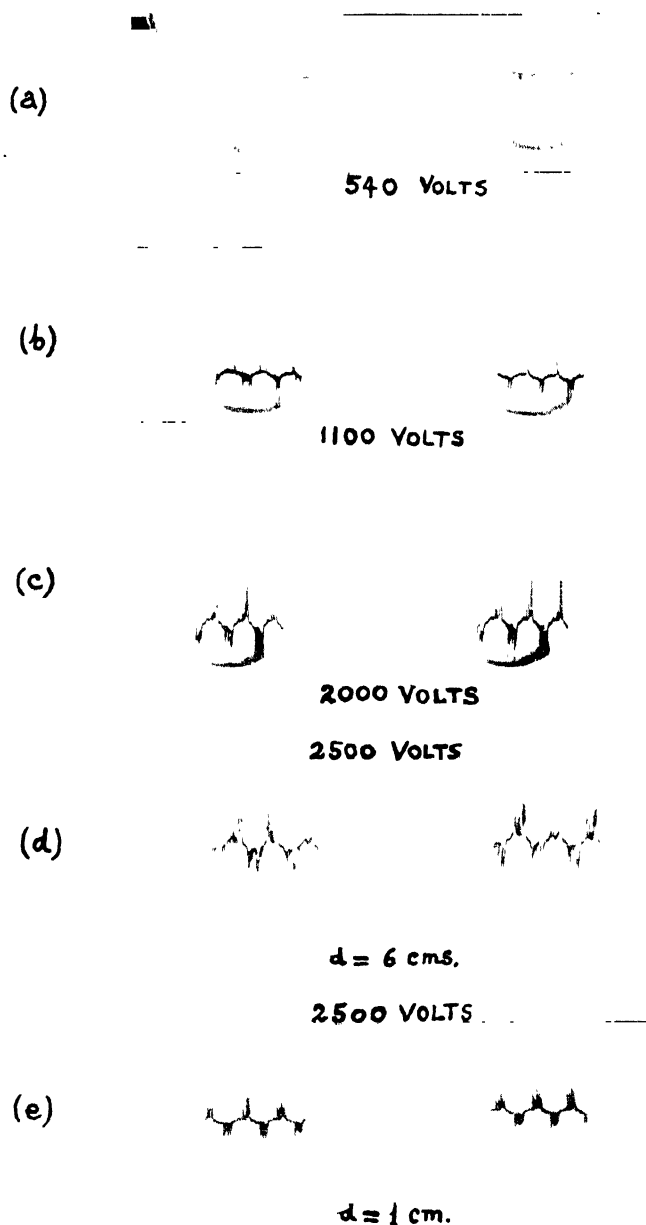


FIG. 2. Oscillograms at different applied voltages of 50 cycles/sec. with iodine vapour discharge tube fitted with external 'sleeve' electrodes.

(a)	Applied voltage:	540 volts.	Inter-electrode distance	8.5 cms.
(b)	"	1,100 "	" "	" "
(c)	"	2,000 "	" "	" "
(d)	"	2,500 "	" "	6 "
(e)	"	2,500 "	" "	1 cm.

The oscillograms in dark are shown on the left and those under light on the right side.

for 2,000 volts show that the 'discharge' pulses disappeared *almost* completely, the remaining mostly Townsend pulses in the dark and that on irradiation the pulses were all Townsend pulses. Oscillograms for a still higher voltage (2,500 volts) with the same discharge tube but with two different distances between the two external 'sleeve'-electrodes, 6 cms. and 1 cm. are shown in (d) and (e) of Fig. 2. For 6 cms. distance between the electrodes it appears that there were only Townsend pulses both in the dark and in light, the 'discharge' pulses having disappeared at such high voltage. For 1 cm. distance between the electrodes, the oscillogram in the dark showed only one 'discharge' pulse in each half-cycle along with the short Townsend pulses and this solitary 'discharge' pulse in each half cycle was quenched on irradiation. It is likely that with a small distance between the electrodes for the same applied voltage, the velocity of the electrodes did not increase sufficiently to overshoot the electrodes, so that the density of charge on the glass surface opposite to either electrode was not *quite* below the requisite value for the discharge or discharges to take place between the opposite charges in the electrical double layer on and near the glass surface. The observed disappearance of the 'discharge' pulses at some high applied voltage in these experiments with iodine vapour discharge tube, where each electrode was at some distance from either end of the discharge tube, is considered as a confirmation of the view that the discharge pulses are associated with the discharge and neutralization of opposite charges in the electrical double layer formed on and near the glass surface opposite to either electrode.

(b) *Nature of the two types of pulses in A.C. 'silent' discharges.*

The nature of the two types of pulses in the iodine vapour discharge tube fitted with external 'sleeve'-electrodes (each electrode being at some distance from either end) was studied by using a high sweep-frequency of the linear time base. In studying the Townsend pulses, the applied voltage was critically adjusted such that, with light shutter closed, there was just the 50 cycle current trace, and with light shutter open, the Townsend pulses appeared on the peaks of the current trace. The oscillogram at such voltage, observed with light shutter open with a high sweep frequency was then photographed. Since the 'discharge' pulses disappeared at some high applied voltage, leaving only the Townsend pulses, the oscillogram at such high voltage when examined with a high sweep frequency gave also the nature of the Townsend pulses. A comparative study of the two types of pulses was also made by observing high sweep-frequency oscillograms at some suitable voltage, where both 'discharge' pulses and Townsend pulses appeared simultaneously with the light shutter closed and the 'discharge' pulses vanished completely with light shutter open. Examined in this way by a suitable sweep-frequency, the pulse of each type was found to have either a *continuous* or an *oscillatory* form. It is however expected that any discharge is of a continuous type when the series-resistance of the discharge circuit has a suitable large value. In the continuous discharge the current at first rises, attains a maximum value and subsequently decreases with time. When however the series-resistance of the discharge circuit has a suitable small value, the discharge assumes a damped oscillatory form. Since the internal resistance of a discharge tube can be considered as a leak resistance R across a condenser of capacitance C through which an A.C. current of angular frequency ω passes, it is evident that the series-resistance r of the circuit, as given by $\frac{1}{\omega^2 CR}$,

must be small or large according as the internal resistance is large or small. Thus a continuous or a damped oscillatory form of discharge may take place for a suitable small or large value of the internal resistance of the discharge tube.

In Fig. 2 are shown some oscillograms of both types of pulses observed with a high sweep-frequency. The oscillograms shown in (a) were observed with a sweep

frequency corresponding to $1,500\mu$ sec., under the same conditions as the oscillograms shown in Fig. 2(e) observed with low sweep-frequency at 2,500 volts, when the distance between the electrodes was only 1 cm. It can be seen that with light shutter closed, only two or three 'discharge' pulses were found along with numerous Townsend pulses. Both Townsend and 'discharge' pulses were found to be of the continuous discharge type. The oscillograms shown in (b) were also observed with a sweep-frequency corresponding to $1,500\mu$ sec. but under different discharge conditions. The applied voltage was 700 volts and the distance between the electrodes was about 8 cms. Both types of pulses appeared in the dark. On irradiation, the 'discharge' pulses vanished altogether but the Townsend pulses persisted. It is significant that the Townsend pulses were found to be of continuous discharge type, whereas the 'discharge' pulses were of damped oscillatory nature. The oscillograms shown in (c) were observed in the dark with sweep-frequencies corresponding to $1,500\mu$ sec. and 500μ sec. respectively. The applied voltage was 1,000 volts and the distance between the electrodes was 6 cms. The internal resistance of the discharge tube was much higher in this case. Both types of pulses were found to be damped oscillatory.

The fact that both types of pulses appeared at the same time, one as *oscillatory* and the other as *continuous* strongly suggests that their origin must be different.

The duration of both types of pulses was found to be between 10^{-3} and 10^{-4} seconds.

4. *Experiments on Joshi Effect as observed by direct measurements of discharge current and by the reception of R.F. oscillations modulated by A.F. pulses in the A.C. 'silent' discharge.*

The experiments were performed with the same iodine vapour discharge tube fitted in the same way as already described, with two external 'sleeve'-electrodes. The experimental procedure has been described in Sec. 2. Two typical sets of experimental results showing (i) discharge currents and (ii) receiver currents with light shutter closed and open at different applied voltages of 50 cycles/sec. are shown in Fig. 4, along with the changes of these currents on irradiation. The distance between the electrodes was 8.5 cms. in the two sets of experiments which were performed one after the other. The radio receiver which was of superhet type (with A.V.C. inoperative) was tuned to one of the R.F. oscillations (5 mc./s.) set up in the discharge tube. The important features in these experimental results are as follows:

(a) At and above 1,800 volts there was no Joshi Effect in either set of experiments, the discharge currents and the receiver currents remaining unaffected by light.

(b) Between 700–1,800 volts there was negative Joshi Effect in either set of experiments. In either set, the reduction in current was found to increase at first with the increase of applied voltage attaining a maximum value and then to decrease gradually with further increase of applied voltage till there was no change at 1,800 volts.

(c) Between 500–700 volts there was evidence of *positive* Joshi Effect in either set of experiments.

We emphasize on the significant fact mentioned under (a) that in both sets of experiments with the iodine vapour discharge tube fitted up with external 'sleeve'-electrodes in the manner already described, the *negative* Joshi Effect was not observed at and above 1,800 volts. As contrasted with these experimental results on the disappearance of negative Joshi Effect at some high applied voltage it can be said that similar sets of experiments with an iodine vapour oscillator showed no such disappearance in the high voltage region, although the observed variation of the negative Joshi Effect with the increase of applied voltage in the ozonizer was

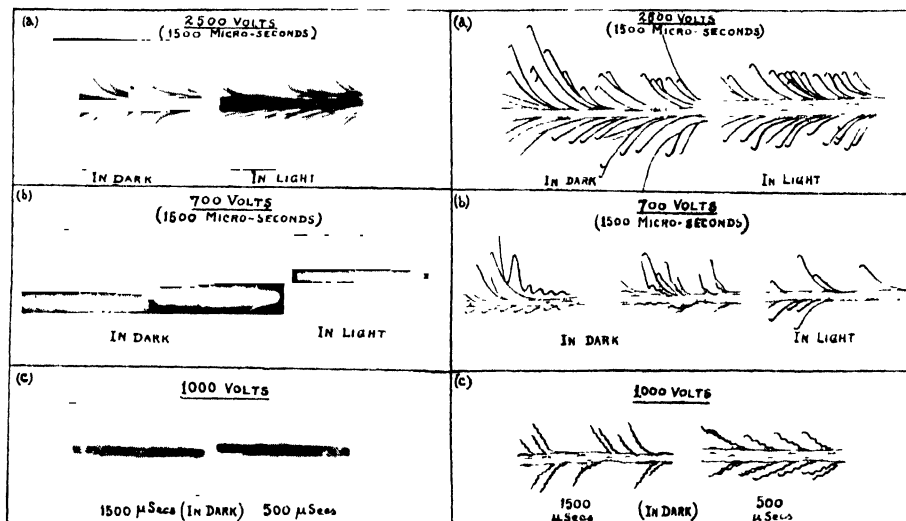


FIG. 3. Nature of the two types of pulses in iodine vapour

- (a) Applied voltage : 2,500 volts (50 cycles/sec.)
Distance between electrodes : 6 cms
Sweep frequency : 6.7×10^2
Both types of pulses are of continuous discharge type
- (b) Applied voltage : 700 volts (50 cycles/sec.)
Distance between electrodes : 8 cms
Sweep frequency : 6.7×10^2
Townsend pulses are of continuous discharge type
'Discharge' pulses are damped oscillatory.
- (c) Applied voltage : 1,000 volts (50 cycles/sec.)
Distance between electrodes : 6 cms
Sweep frequencies : 6.7×10^2 and 2×10^3 .
Both types of pulses are damped oscillatory.

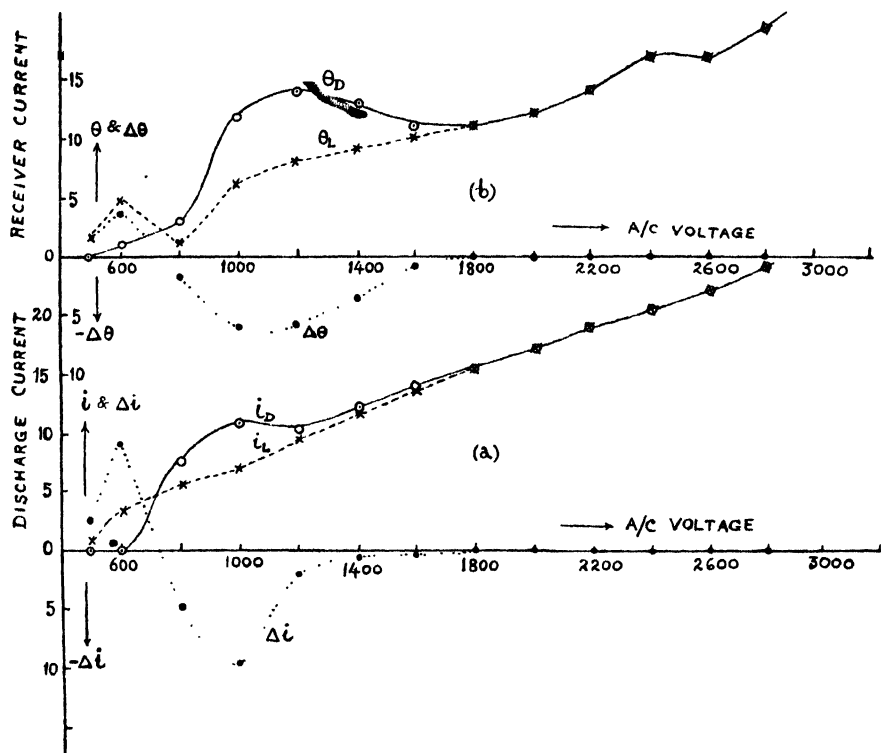


FIG. 4. Experimental results with Iodine vapour 'sleeve'-discharge tube. Distance between external 'sleeve'-electrodes: 8.5 cms.

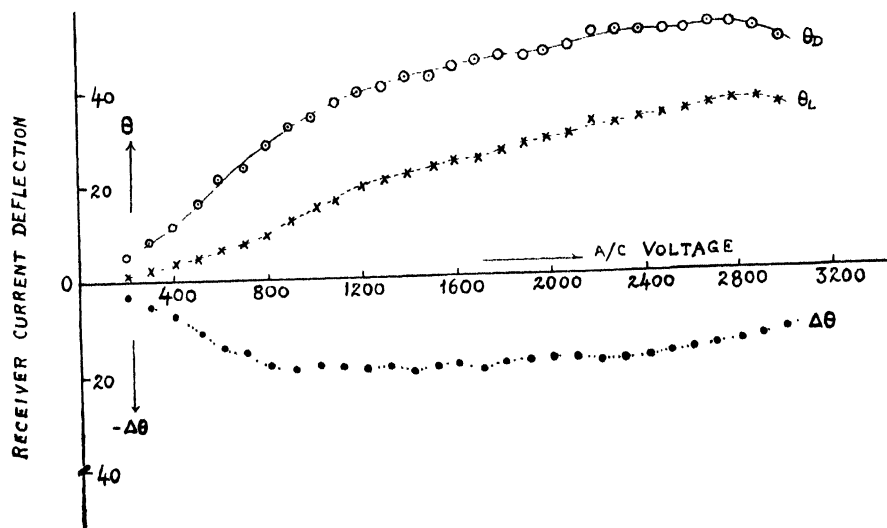


FIG. 5. Receiver results with Iodine vapour ozonizer. (Receiver tuned to 9 mc./s.)

otherwise similar to that observed in the 'sleeve'-discharge tube. A typical set of results of the receiver experiment with an iodine vapour ozonizer is shown in Fig. 5. (The positive Joshi Effect was however not observed in this set of experimental results.) We are inclined to the view that the disappearance of the negative Joshi Effect in the iodine vapour 'sleeve'-discharge tube at some high applied voltage is associated with the disappearance of the 'discharge' pulses at such high voltage. We are also inclined to the view that the appearance of the negative Joshi Effect in iodine vapour at a critical voltage is due to the occurrence of the 'discharge' pulses. This is consistent with the variation of the negative Joshi Effect with applied voltage observed in both sets of experiments. The variation of the negative Joshi Effect with the applied voltage has been fully discussed elsewhere (Khastgir and Setty, 1952).

It is to be noted that the appearance of the 'discharge' pulses at some critical voltage in an ozonizer or in a 'sleeve'-discharge tube filled with iodine vapour is characterised by a loud noise in the loudspeaker at the output of the radio receiver. The disappearance of the 'discharge' pulses at some high voltage in a 'sleeve'-discharge tube is also associated with the cessation of the loud noise in the loudspeaker of the radio receiver. The positive Joshi Effect in iodine vapour near the 'threshold' potential which is due to the initiation of Townsend pulses by light is also indicated by a characteristic sound in the loudspeaker of the receiver.

We have already shown (Khastgir and Setty, 1952) that the R.F. oscillations in the A.C. discharge are modulated by the Townsend and 'discharge' pulses. In a superhet receiver, it is known that for small modulation depths, the rectified output due to the received modulated signal is proportional to the amplitude of the 'carrier' oscillation only. In the receiver experiments, however, the R.F. oscillations were found to be modulated by these A.F. pulses much above 100%. In the case of such over-modulation, the rectified output in the receiver depends on the amplitudes of both the 'carrier' oscillations and the modulating pulses. It cannot therefore be stated with certainty that the amplitude of the R.F. oscillations in the A.C. 'silent' discharge is decreased or increased by irradiation, when a decrease or increase in the rectified output is actually observed. The change in the rectified output may as well be due to a change in the amplitude of the modulating pulse.

5. CONCLUSIONS.

The experimental results given in the paper lead to certain conclusions regarding the origin of Joshi Effect in iodine vapour under 'silent' electrical discharge. The conclusions may also be generalized. These conclusions are:

- (i) In the 'silent' electrical discharge there are two distinct types of current pulses.
- (ii) The two types of pulses appear to be of different origin.
- (iii) The duration of these pulses corresponds to an audio frequency of 10^3 - 10^4 cycles/sec.
- (iv) The positive Joshi Effect observed near the 'threshold' potential is due to the initiation of what have been called the Townsend pulses by the incidence of light.
- (v) The negative Joshi Effect in iodine vapour is mainly due to the photo-suppression of what have been called the 'discharge' pulses.
- (vi) The R.F. oscillations of discrete frequencies which are set up in the 'silent' discharge are modulated by the A.F. pulses and the modulated R.F. oscillations, as detected by a radio receiver may show positive and negative Joshi Effect under suitable conditions.

It is considered likely that the physical processes suggested by Joshi (1946, 1947) and his collaborators (Joshi and Lad, 1945; Ramana Rao and Kanawar

Sarma, 1949; Arnikar, 195.) and by Harries and Von Engel (1951) may be operative under suitable experimental conditions, quite apart from what we have formulated.

In conclusion, we accord our sincere thanks to Dr. S. S. Joshi, D.Sc. (Lond.) for kindly supplying us with discharge tubes and accessories and for his active and helpful interest in the work.

ABSTRACT.

Some experimental results with iodine vapour at saturation pressure inside a discharge tube fitted with external 'sleeve'-electrodes and excited by varying voltages of 50 cycles/sec. are given in the paper. The results have shown two distinct types of current pulses in iodine vapour under 'silent' electrical discharge. The oscillographic evidence strongly suggests that the two types are of different origin. The observed positive Joshi effect near the 'threshold' potential is attributed to the initiation of what have been called the *Townsend pulses* by the incidence of light and the observed negative Joshi Effect is considered as *mainly* due to the photo-suppression of what have been called the '*discharge*' pulses. The experimental results confirm the view regarding the origin of the 'discharge' pulses. An account is also given of parallel sets of experimental results on Joshi Effect observed by directly measuring the discharge current and also by detecting in a radio receiver the R.F. oscillations as modulated by the A.F. pulses in the 'silent' discharge.

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PHYSIOLOGICAL DYNAMICS OF CELLS ISOLATED FROM CHICK EMBRYOS *

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INTRODUCTION.

The viewpoint of the experimentalist towards differentiation is a dynamic one. It concerns mostly with the physiological behaviour of embryonic cells. The growing tendency to realize the importance of cell surface in the function of tissue differentiation has made its mark in all quarters of embryology (Weiss, 1949). By recent technique of direct observation, cells can now be better analysed in their functional state. The simple procedure of cell dispersal and dissociation, experimented largely upon amphibian types by Holtfreter (1949), seems to have an equal applicability to other types of embryonic cells.

The chick embryonic cells, ranging next to amphibia, have been utilized for cell dissociation experiments. The physiological dynamics of them have been studied after the intercellular matrix has been experimentally disrupted. Such experimental dissociation is advantageous not only because it affords a study of the dynamics in isolation but also it makes physiological excitation possible to the cells. It is likely that under such experimental set-up, the properties of the surface layer of cells would be accessible in throwing light on their morphogenetic significance in tissue differentiation.

EXPERIMENTAL.

In order to study the behaviour of embryonic cells in isolation, chick embryos are raised up to the stage of gastrulation. The entire embryo or a desired part of it has been subjected to chick Ringer solution whose pH has been raised just over 9 by the appropriate administration of KOH. The alkaline pH of the physiological solution between 9 and 9.2 has been shown to be a potent cell-dissociating agent. Within the lapse of a few minutes of introducing the cells in the alkaline medium, they start falling apart singly or in odd groups. The high pH treatment, as it appears, dissolves the intercellular matrix of cells. The separated cells show certain noteworthy physiological dynamics. To facilitate observation, these cells with the help of micropipette, are transferred to culture slide. Under sterile condition cells can be observed for a long time. Mostly ordinary microscopic studies have been made except in a few occasions when phase microscopic studies have also been made.

The sterile technique of chick tissue culture, as far as possible, has been followed. In a few cases, however, the dissociated cells are fixed in Zenker's fixative and stained in diluted Delafield's haematoxylin for further studies.

* A preliminary report of this work appeared in the *Nature*, 171, p. 796, May 2, 1953.

RESULTS.

Disintegration of the intercellular matrix by the alkaline exposure.

The intercellular matrix is important because it appears to hold the cells together during the tissue formation. In a sense, the cementing substances between embryonic cells allow a group of cells to maintain their contiguity which is essential in the making up of any pattern. Experiments with chick embryos show that the ground substance between cells can be disintegrated by the high pH of the physiological solution. It appears there must have been some physiological processes operative in the excess of alkali to remove the intercellular substances of the reacting cells of an embryo. This becomes evident because the cell to cell attachment is dissociated and as a result cells tend to lie separated from one another (Pl. XXXII, Fig. 5). The cells of the periphery separate first and this tendency after a little while becomes gradually evident in the cells of the middle mass. There are always some cases in the experimental series where a few cells continue to cluster together and some of them do not dissociate completely (Pl. XXXII, Fig. 7). Presumably these are the instances where the intercellular connections have not been completely loosened out. The tendency of cell-dissociation has been observed to be a common criterion both in embryonic as well as in the extra embryonic regions.

Surface activities of the dissociated cells.

Constant observation reveals that the isolated embryonic cells become more active with their surface layers on. The identity of the surface layer from the rest of the cell contents in these cells becomes clear (Pl. XXXII, Figs. 1 and 6). The distinct appearance of the limiting membrane which was not visible before can only be attributed to some sort of separation of the layer from the granular cytoplasm. Observation shows that such cells take up more water and swell to an appreciable extent. The hydration of cells presumably becomes possible by the presence of H_2O molecules in between the ectoplasmic layer outside and the granular cytoplasm inside (Pl. XXXII, Fig. 4). The intake of water and the surface mobilization seem to occur simultaneously to these dissociated cells. The surface layer activity appears in the form of pseudopodial bulge. It may be located at a point or may very well rotate round the cell. The surface layer may involve into quick hyaline bulge formation and simultaneous disappearance. Thus its appearance takes place at random. Instances have been recorded where such an extension of the surface may be protruded out in a stationary way without much of further mobilizations at other places. However, rapid cell dynamics may make the cells shape variable until it again becomes almost round. At times it has been observed that the surface mobilization may take the form of needle-like projections which are also retractable. The activity of the surface layer in some way or other appears to be related to another important criterion, namely, the question of permeability (*vide infra*).

The internal morphodynamics of cells.

Besides the surface mobilizations, cells also exhibit certain morphodynamics of their cytoplasmic contents. The inside material of the cell appears to be in a whirlpool of movements. The nucleus can well be recognized within the granular cytoplasm (Pl. XXXII, Fig. 2) even when the whole thing is undergoing displacement. Is the random movement of cytoplasm more than the Brownian movement? The internal morphodynamic may or may not be accompanied with the surface activity. It has been observed that the granular cytoplasm of cells may at once change into homogeneous mass. This may be the case of sol-gel formation of the cytoplasm.

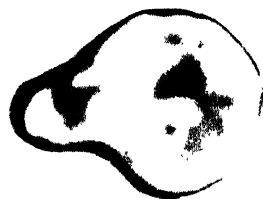
Over-alkaline exposure liquefies the cell wall. The alkaline exposure beyond the range of 9.5 is liable to disintegrate the cell wall at once. The surface mobili-



1



2



3



4



5



6



7



8

zations and other physiological dynamics are best shown between the pH 9 and 9.2. The result of continuous alkaline exposure even within the safe pH of 9 will go on increasing the permeability of the cell. The cell surface seems to react physiologically at the beginning to alkaline treatment but becomes later increasingly permeable so that large intracellular contents have been observed to leak out from it. This continuous process of evacuation of the intracellular particles through the cell wall makes the cytoplasmic concentration gradually weaker (Pl. XXXII, Fig. 3).

The alkaline exposure, if maintained continuously, seems to make the cell surface weak and not long durable in this medium. The surface layer may soon be liquefied and bring about a complete disintegration of the cell structure. Similar results of an immediate liquefaction of the cell may be obtained if to start with the pH range is taken beyond 10.

Lowering of the hydroxyl ion concentration decreases the surface activity and permeability of the cells.

Isolated cells, when they are at the height of their dynamics, may immediately decrease their surface mobilization following the lowering down of the pH of the saline solution. Similar phenomenon of forthwith cessation of the surface activity seems to happen even to those cells which have lost quite a bit of their intracellular contents (Pl. XXXII, Fig. 4). The fact becomes clear when the surface activity becomes absent the intracellular contents cannot escape from the cell, i.e., the permeability of the cell surface becomes checked. The general volume of the cell also gets reduced presumably by a process of some dehydration. The protruded surface layer gradually recedes and it seems to sit tight over the granular cytoplasm.

The pH manoeuvres to initiate or to stop the cell activity may have some influence upon the differentiating trends of cells. The alkaline shocks, as it appears, may be subjected in a sublethal manner and there are possibilities of microscopic as well as sub-microscopic changes being resulted from it. Fixed preparations of such cells show (Pl. XXXII, Fig. 8) occasional fragmentation of the nuclear material and the lesser localization of the cytoplasmic ingredients. It is yet to be seen how far the apparent normalcy to these sublethally cytolyzed cells is physiologically true.

DISCUSSION.

Experimental dissociation of cells in chick embryos, brought about by the alkaline exposures, clearly demonstrates the fact that there is a similarity of physiological reactivity in different vertebrate embryonic cells towards alkalinity. The high alkalinity causes a swift disintegration of the intercellular matrix of the chick embryonic cells as well as of amphibian cells (Holtfreter, 1949). This is perhaps the reason why the cells are separated singly. The possibility suggests itself to speculate about the presence of similar properties of cell surfaces during the embryonic stages. This idea gets a support from our work that the cells of the extra embryonic and the embryonic regions behave more or less in a similar way so far as their surface activities are concerned. In this respect the cell dissociation from late embryonic development of chick embryos obtained by Moscona and Moscona (1952) is also interesting.

The two facts, namely, the dissociation of cells and their surface activities are items of careful consideration. It is probable that they are not only interrelated but perhaps interdependent. How does excess of alkali sweep out the ground substance between cells? Is it that the disruption results from the solubilizing effects of the high pH upon the ground substances? We have observed that these cells, after dissociation exhibit a series of physiological dynamics. Concurrently cells appear to be more hydrated. It is natural to expect that the permeability of

the cell surfaces must have been increased. If the permeability is allowed to go on increasing it is bound to lead to a complete collapse of the cell structure.

It is likely that the question of permeability of these cells is bound up with that of the surface layer of the protein molecules which may act as an osmoregulatory door-way of intake of water molecules. Discussing the folding and unfolding of protein molecules as a basis of osmotic work, Goldacre (1952) suggests that there is always some sort of enzyme reactions involved in the process of osmoregulation. As for the exact mechanism we have yet to search for it. We may well pose the other side of the problem of osmoregulatory mechanisms of cells. We have witnessed that there is an indication of a reversible sort of change in the cell nature which may happen during a change from alkali to acid pH . The active mobilization of the surface layer and its subsequent inactivation by the lowering of pH could well be taken as a change much more implied than only having osmoregulatory importance. Holtfreter (1949) believes that monovalent cations and hydroxyl ions stimulate phosphatide hydration, decrease adhesiveness and expansion of the cell membrane. With his studies on the cell migration of the neural crest in confined spaces, Flickinger (1952) upholds the observation of Twitty (1949) that a pH gradient across the cells is responsible for negative cell affinity and amoeboid movements *in vitro*. Mookerjee, Deuchar and Waddington (in the Press) have investigated the properties of electrolytic conditions upon the cell attractions of the developing notochordal tissue.

Certain mathematical postulations by Opatawski (1951) on the permeability coefficients of the erythrocytes may be considered in this connection. He thinks that the relationship between the pressure and the concentration during the process of diffusion is ruled by the law of perfect gases and he has accordingly deduced an equation. The theoretical deduction stands on the merit of the idea that change in the cell volume is unaccompanied by changes in the stress of cell membrane—which is dependent on a constancy of the external and internal pressures. It will be most interesting if such theoretical deductions are also workable in our isolated chick embryonic cells. That would mean a step forward in the experimental analysis of the osmoregulatory properties of embryonic cells.

It is likely that this change over from alkalinity to acidity brings forth a condition of sublethal cytolysis to these cells. The growing importance of sublethal cytolysis in tissue differentiation—particularly in neural differentiation—stressed by Holtfreter (1949) may be well studied from these chick embryonic cells. Brachet (1952) is of the opinion that amoeboid movements require a very low uptake of oxygen. During this period of low physiological state of existence of the alkali treated cells, there is a chance of initiating some enzymatic disturbance—qualitative or quantitative (Mookerjee, unpublished)—to be reflected on the morphogenetic significance of them.

SUMMARY.

1. The chick embryonic cells at the gastrula stage have been experimentally dissociated by the high alkaline exposures varying from pH 9 to 9.2.
2. The dissociated cells show physiological dynamics—in surface layers and in the cytoplasm.
3. The high alkali renders the greater permeability of the cell surface which may again be decreased if the cells are put back in normal or in slightly acid Ringer solution.
4. The probable mechanism of cell permeability has been discussed where the folding and unfolding of protein molecules through enzyme action have received attention.

ACKNOWLEDGEMENT.

The author is grateful to Dr. Subodh Mitra, Director, Chittaranjan Cancer Hospital, for providing laboratory facilities.

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PLATE XXXII.

EXPLANATION OF FIGURES.

Phase-photomicrographs of chick embryonic cells—

- FIG. 1. A living cell with the surface layer mobilized in the form of a pseudopodial bulge ($\times 1400$).
- „ 2. A dissociated cell without surface mobilization, the nucleus and the cytoplasmic granules clearly seen ($\times 1400$).
- „ 3. A living isolated cell, most of its cytoplasmic material evacuated but the surface activity continues to operate ($\times 1400$).
- „ 4. A living cell, very much hydrated, no surface activity, evacuation of large portion of the cytoplasmic granules and presence of water inside the cell mass ($\times 1400$).
- „ 5. A group of fixed cells dissociated with the surface activity on them ($\times 600$).
- „ 6. A living cell with two tiny pseudopodial bulges ($\times 1400$).
- „ 7. A group of living cell mass gradually dissociating by the disruption of the intercellular matrix ($\times 600$).
- „ 8. Fixed cells experimentally dissociated and in many of them nuclear material fragmented ($\times 1000$).

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INDUCTIVITY AND PLASTICITY OF THE VENTRAL BLASTOPORAL LIP CELLS

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INTRODUCTION.

In recent years our interest in the ventral blastoporal cells has been revived once again by the experiments of Yamada (1950). It is a common knowledge that the ventral blastopore cells are the counterpart of the dorsal blastopore of a gastrulae and in the process of neural induction they do not, as a rule, take part in this process of differentiation. The histological patterns that emerge out from the invagination of the ventral lip cells are the mesenchyme, blood islands and some other endodermal derivatives. But under a certain condition of alkalization, the ventral blastopore cells can be made to differentiate into notochord and somites as obtained by Yamada (1950). Keeping these remarkable developmental capacities in mind, translocation experiment has been conducted upon a gastrulae where the organizer has been replaced by its counterpart, the ventral blastopore. Interest will be focussed round these experiments, in order to know what happens when ventral blastopore replaces the dorsal blastopore and if there is any sort of normal induction resulting from the effects of the ventral blastopore upon the dorsal ectoderm. The ventral blastoporal cells have also been subjected to derivatives of the nucleic acids, citric acids and to some other conditions in isolation. There is reason to believe that these experimental designs would lead us to a better elucidation of the problem of the cellular plasticity and inductivity of the ventral blastopore of a gastrulae.

The author is grateful to Professor Jean Brachet for his interest in this work and also for his kindness in going through the manuscript of this article.

MATERIAL AND METHOD.

The embryos of *Triturus alpestris* constitute the material of this study. Thirty-four successful grafting experiments have been done where the medio-ventral marginal zone of a gastrulae in the form of rectangular body has been placed in the vacated portion of the organizer of another gastrulae.

Another set of experiments concerns with the isolation of the ventral blastopore cells of the gastrulae which were subsequently cultured in 1/10th Holtfreter's solution containing some special chemicals. The Guanylic acid, citric acid, lithium choline and urea (for proportion see experimental results) have been used in the culture solution. Besides these, thermal exposure has also been used in the isolated cells of the ventral blastopore.

After the embryos and the isolates have been operated and kept alive for the desired length of time, they were fixed in Zenker's solutions. They were washed

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thoroughly in water before they were graded through alcohol and paraffin. The sections were prepared at 10μ thick and stained with Toluidine Blue.

EXPERIMENTAL RESULTS.

Doubling of the neural axis by the transplantation of the ventral blastopore in place of the organizer.

Whenever there has been a translocation of the ventral blastopore in place of the dorsal lip there has been always a tendency of doubling of the neural axis. The experimental animals, after being histologically analysed, reveal that the doubling nature is not an uncommon feature of most of them. Out of thirty-four cases, 25 are associated with some form of duplication of the neural axis. All are not of one category but in fact are representatives of a series of the neural duplication.

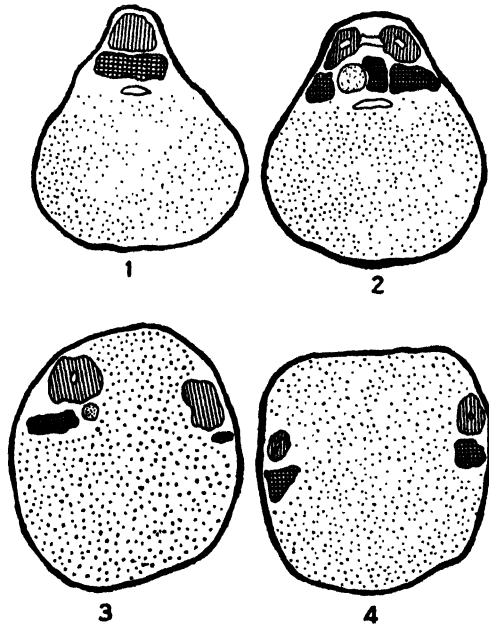
A case, typical of one class of doubling, encountered in this study has been depicted in Fig. 3. The interest in such cases lies on the fact that the two widely separated neural areas seem to occur on the two lateral extremities of the embryo. Out of the two neuralized area, the one which is seen on the left hand side, appears to be better formed to the stage of neural tube. The neurocoele within it is clearly visible. A comparatively smaller notochord lies beneath the neural tube with some mesodermal cells. The archenteron cannot be marked out definitely. The nature of the neural structure on the other side, occupying the right hand side, has been represented by a solid thickening of the ectoderm. No notochord can be traced out near the thickening ectodermal mass. This thickened ectodermal area seems to be slightly better developed than a pallisade condition but definitely underdeveloped of perfect neural nature. Significantly enough, the middle region where the graft has been put, is devoid of any other tissue except for some yolky endoderm. The place of normal appearance of the axis remains strangely endodermal. The presence of this dorsal endoderm makes a sort of a partition between the two laterally disposed neural areas. Another class of embryos slightly different in the nature of the doubling of the neural axis has been depicted in Fig. 4. There are two neural tubes with a neurocoele in each of them. Two tubes are of unequal size. The one on the left is much smaller than its counter part of the right. The absence of any notochordal cells in the vicinity of two neural tubes are facts of importance. The neural tubes are again widely separated by the intervention of yolky endoderm.

The other type of doubling, occurred only in a few cases may be discussed here. This type has been represented in Fig. 2. The special interest of this neural structure is that there are two canals observed in a single large mass of a neuralized area, i.e. two tubes occur in a fused condition within a common area. A tiny layer of the ectodermal tissue is interposed in between the two neuralised areas. The presence of this layer makes a discontinuity of the neural structure induced. The notochord is visible with a mass of mesodermal cells between the neural structures. It seems that yolky endoderm cells have not been represented here at this level of embryo.

Absence of any neural axis following translocation of the ventral blastoporal cells in place of the organizer.

Majority of the cases with our translocation of the ventral blastopore in place of the dorsal, have resulted in the doubling of the neural axis but only in a few cases the results also show certain other variations. These results are different in the sense that there is a tendency of suppression of neural structures. A representative case has been shown in Fig. 1. The figure renders the fact clear that there has been a very weak mobilization of the ectoderm cells at the mid-dorsal

side of the embryo; a place where normally the neural tube appears. The neuralization has failed to react in these circumstances and a condition of pallisade has resulted. The underlying tissue of the thickened area mostly are represented by loose mesodermal cells. Neither notochord nor somites are visible. In very rare cases distinguishable archenteron is observed. The fact becomes clear that the evocatory action in some way or other is hampered.



All are schematic representations of the operated embryos at tail bud stage.

- FIG. 1. Cross-section of an embryo in which the organizer has been replaced by the ventral marginal zone. Note the under-development of the neural tissue and the fusion of the mesodermal area.
- „ 2. Cross-section of a similar graft. Note the doubling of the neural axis interposed by a band of thickened ectoderm and three somital blocks and a chorda.
- „ 3. Cross-section of a double axis separated by the yolk endoderm. Note the large size of the neural tube on the left hand side with the chorda and one somite block; the pallisade condition of the neural on the right with a somite block.
- „ 4. Cross-section of the embryo with two axes. Note the presence of small neurocoele in both the neural tubes and absence of chorda under them.

Isolated ventral blastopore cells exposed to various physiological conditions.

(a) In acidified Holtfreter solution.

The ventral blastopore cells after isolation, have been cultured in 1/10 Holtfreter solution containing .3%, .5% and 1% of Guanylic acid. Cells have been kept in the acidified solution for varied length of time. The minimum time of exposure was $\frac{1}{2}$ a minute while some of them have been cultured continuously. Histological sections show that the development of these cells has not proceeded and has been blocked. Similar experiments with citric acid (pH 2.3 and 4.2) have also been done. Here the time of exposure is cut down to few seconds but the differentiation is blocked. Experiments with distilled water also give a similar picture of blocked development.

(b) *Holtfreter solution with lithium chloride and urea.*

In Holtfreter's solutions containing 4% lithium chloride and 1.25% of urea the ventral blastopore cells when cultured, the trends of differentiation is blocked. The deleterious effects hinder the process of development, even epidermal type of differentiation is also incapable of formation.

(c) *Thermal exposure to the ventral blastopore cells.*

The ventral blastopore cells, after isolation, have been exposed to 30°C. and 34°C. of temperature. The temperature shocks make the cells incapable of further differentiation. The development has been retarded completely.

DISCUSSION.

The main evidence emerged from these experiments will favour us to regard the ventral blastopore as an ineffective inductor in place of organizer. This seems to be true because straightforward induction seldom happens from the ventral blastopore upon the gastrular ectoderm. Great many cases of our experiments with the ventral blastopore have resulted in the production of two neural axes instead of one. This duplication of axis, however, does not account for any evidence of inductive capacity of ventral blastopore cells. Induction, seems to be always absent at the normal position of the embryo. But the translocated cells of the ventral blastopore, may be credited that it has managed to fragment the one organizer action into two. In a previous study, Bautzmann (1932) has been able to show that the 'Randzone' when transplanted in place of the organizer, duplication of the axis may result. Parallel results in chick embryos, have been encountered in the experiments of Abercrombie and Bellairs (mentioned by Waddington, 1952).

The presence of the ventral blastopore cells in the organization centre, appears to break up the unitary action of evocator by being itself non-inductive. Moreover, the translocated cells possibly cannot be assimilated in the induction-system and that is why their presence amount to fragmentation of the inducing centre. With the removal of the organizer cells, the remaining cells of the mesoderm presumably acquire a better inductive-state because some non-inductive material have taken the place of the original high gradient. In terms of Yamada's (1940) 'high' and 'low' gradients, it could be explained by certain theoretical postulations. Mookerjee (1953a) has already put forward the latero-dorsal topographic relations in inductive process. His idea of 'position-effects' can be brought in the present cases of double axis. The other type of lowly induced neural structures can be explained better if one thinks that the grafts possibly could not be assimilated and invaginated properly during gastrulation. It is likely that the organizer centre, represented here only by the remaining cells of the mesoderm (ineffective inductor, as shown by Waddington, 1936 and by Mookerjee, 1953a) could not induce a better type of neural structures.

The mode of differentiation of the ventral blastopore in these grafts does not give the impression that they can be easily differentiated into notochord structures. Yamada (1950) has got them to differentiate into notochord by a cytolytic process of alkalization. The series of experiments that we have conducted do not make much room for the idea that under the experimental conditions in our materials, they become chorda-wise. The process of dorsalization as Yamada has been able to produce, seems to be resulted from a particular type of reaction, perhaps provided by the action of the alkali upon his cells. Mookerjee (1953b) has entertained such an idea of specific 'type' of reaction and the mode of differentiation produced. Thus the negative results will not minimise but in fact strengthen the idea of Mookerjee that sublethal cytotoxicity, not all cytotoxicity, can bring about a directive

change in tissue differentiation. The other possibility which should not be ignored is the specific difference of the material studied. Yamada's *T. pyrrhogaster* may have a special susceptibility to dorsalization than the cells of *T. alpestris* studied by us.

SUMMARY.

- (1) The ventral blastopore of a gastrulae when replaces the dorsal lip of a gastrulae, cannot bring about neuralization by itself.
- (2) The doubling of the neural axis is the outcome of the implantation of the non-inductive ventral blastopore.
- (3) The doubling phenomenon has been explained by supposing that the two lateral halves of the mesoderm become inductive in the presence of a non-inductive material in between them.
- (4) Theoretical implications about the position effects in the process of induction have been discussed.
- (5) The differentiation of the ventral blastopore cells are not 'dorsalized' either by implantation or by physiological treatments of some category.

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EXPERIMENTAL TESTS OF THE MODIFIED CLAUSIUS-CLAPEYRON RELATION FOR IDEAL MULTI-COMPONENT MIXTURES

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INTRODUCTION.

There exists in the literature, a large amount of experimental data on binary and ternary mixtures both ideal and non-ideal, but very little attempt seems to have been made to interpret and correlate these data in the light of modern thermodynamic theory. The present authors have recently extended the purely thermodynamic theory of Gibbs to the case of systems of any number of components and obtained the general conditions of equilibrium between the condensed and vapour phases for such systems. In particular the modified Clausius-Clapeyron relation for systems of any number of components was derived and several limiting cases discussed (Srivastava and Rastogi, 1953). This paper hereafter will be referred to as paper I. It is the purpose of the present paper to test the various formulae developed in paper I, for ideal liquid mixtures. In particular, equations I (32), (41), (42), (45), (46), (47) and (50) have been tested with respect to several mixtures already known to be ideal, thereby confirming the ideality of these mixtures and simultaneously proving the validity of these formulae.

2. MODIFIED CLAUSIUS-CLAPEYRON RELATION FOR AN IDEAL LIQUID MIXTURE.

The experimental data on systems of more than three components is very scarce and therefore, in this paper we confine our attention only to binary and ternary systems.

It was shown in paper I, that equations I (45) and I (46) are identical in the case of ideal mixtures, and yield

$$\frac{1}{P} \frac{dP}{dT} = \frac{N_1' L_1^\circ + N_2' L_2^\circ}{RT^2} + \left(\frac{N_1'}{N_1} - \frac{N_2'}{N_2} \right) \frac{dN_1}{dT}, \quad \dots \quad (1)$$

which is the modified Clausius-Clapeyron's relation for an ideal binary liquid mixture. This we now proceed to test with reference to the systems Ether-benzene, Toluene-carbon tetrachloride and Benzene-Toluene all of which are known to be ideal.

Ether-Benzene.—The data given by Schmidt (1926) for this mixture have been plotted in Fig. 1 for different mole fractions of ether in the liquid mixture. From this graph the change in total pressure δP for a change of temperature by 10° and a change of concentration δN_1 of ether by 0.2 mole fractions was read out at different points on the curves giving $(\delta P)_{\text{obs.}}$. Next N_1' and N_2' were calculated by making use of Raoult's law and δP calculated from equation (1) for the given changes in T and N . The latent heats at different temperatures were read out from a rectilinear graph giving L at different temperatures. The observed and calculated values of δP are given in the last two columns of Table 1, and are seen to show striking agreement, thereby proving the validity of equation (1).

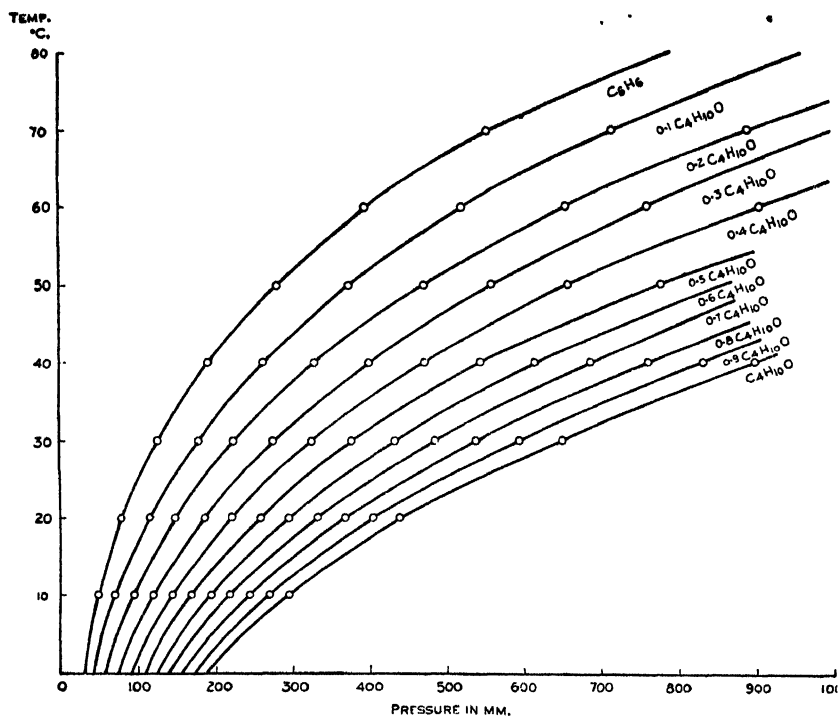


FIG. 1.

TABLE 1.

System.	N_1	N_1'	$T^\circ \text{K.}$	L_1° cal./gm. mol.	L_2° cal./gm. mol.	dP (obs.) (mm.)	dP (calc.) (mm.)
$\text{C}_4\text{H}_{10}\text{O}-\text{C}_6\text{H}_6$..	0.2	0.5570	313	6,110	7,840	260.5	261.8
" ..	0.3	0.7163	303	6,300	7,970	212.5	209.1
" ..	0.7	0.9217	293	6,490	8,100	210.0	203.1
$\text{C}_7\text{H}_8-\text{CCl}_4$..	0.5	0.2280	313	8,950	7,575	90.0	92.9
" ..	0.6	0.3154	323	8,800	7,450	120.0	118.6
" ..	0.8	0.5123	303	9,100	7,700	48.0	47.8
$\text{C}_6\text{H}_6-\text{C}_7\text{H}_8$..	0.3	0.5432	313	7,840	8,950	68.0	67.2
" ..	0.5	0.7010	303	7,970	9,062	54.0	52.7
" ..	0.8	0.9010	323	7,710	8,837	125.0	127.7

Toluene-Carbon tetrachloride.—The data for this system are given by Schmidt (1926) and are plotted in Fig. 2. The calculated and observed values of δP are given in Table I and are seen to be in close agreement.

Benzene-Toluene.—The data for this system given by Schmidt (1926) are plotted in Fig. 3, and the calculated and observed values of δP are given in Table 1. Thus the validity of equation (1) is clearly shown by Table 1, which, at the same time, serves to show that the systems considered are ideal.

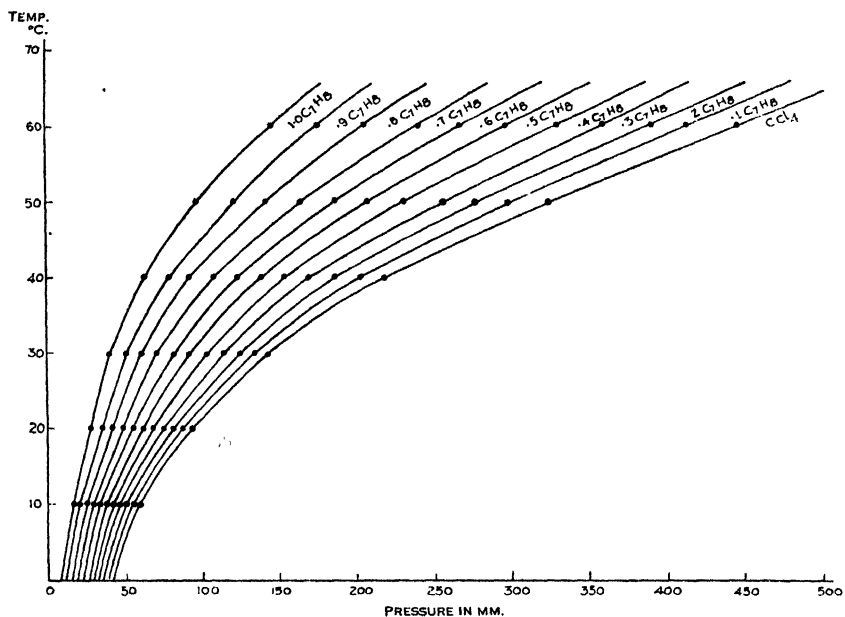


FIG. 2.

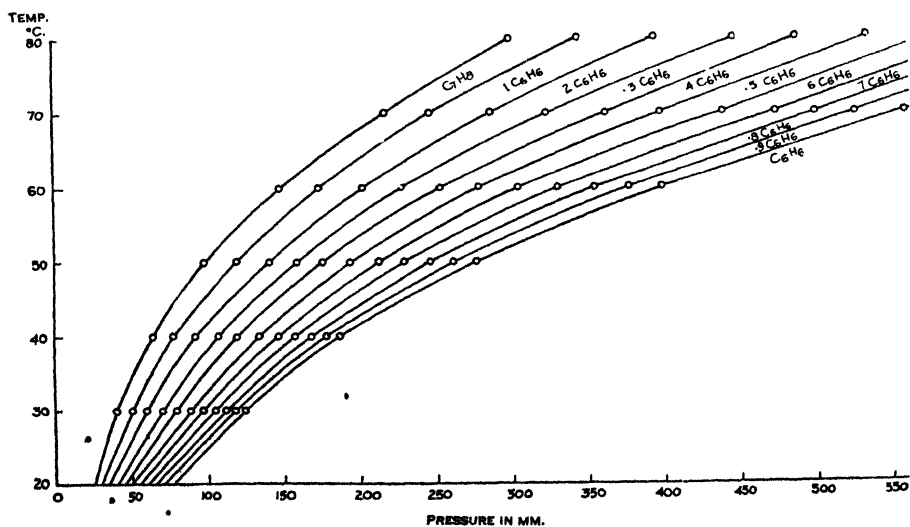


FIG. 3.

3. ISOBARIC TRANSFORMATIONS.

Equation (1) or I (47) for this case yields

$$\left(\frac{\partial N_1}{\partial T}\right)_P = -\frac{N_1' L_1^\circ + N_2' L_2^\circ}{RT^2} \cdot \left(\frac{N_1'}{N_1} - \frac{N_2'}{N_2}\right) \quad \dots \quad (2)$$

To test this equation, Figs. 1, 2, 3, were utilized to give for certain fixed pressures, values of N_1 and the corresponding temperatures, and these are plotted in Fig. 4 for these three systems. Drawing tangents at various points of the curves in Fig. 4 the experimentally observed values of $(\partial N_1 / \partial T)_P$ were found and these compared with the values calculated from equation (2). The results are given in Tables 2, 3 and 4 and show very good agreement.

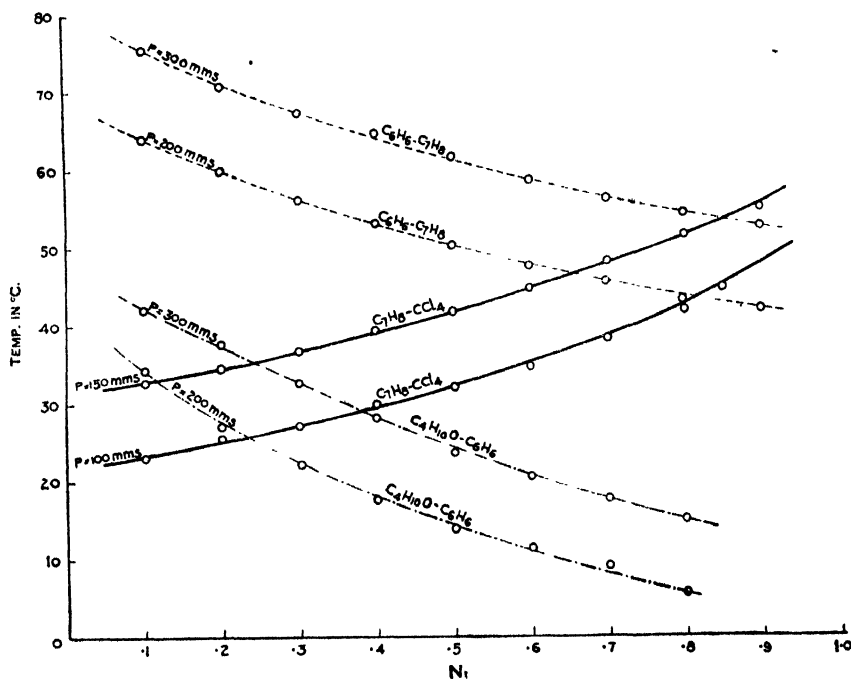


FIG. 4.

TABLE 2.—Ether-Benzene mixture.

P (mm.)	N_1	N_1'	$T^\circ \text{K.}$	L_1° cal./gm. mol.	L_2° cal./gm. mol.	$\left(\frac{\partial N_1}{\partial T}\right)_P \times 10^5$ (calc.)	$\left(\frac{\partial N_1}{\partial T}\right)_P \times 10^5$ (obs.)
200 ..	0.1	0.4000	307.0	6,250	7,920	1,154	1,150
" ..	0.3	0.7200	295.0	6,480	8,050	2,076	2,162
" ..	0.5	0.8750	287.0	6,600	8,170	2,777	2,758
" ..	0.7	0.9450	281.0	6,710	8,250	3,712	3,636
300 ..	0.2	0.5200	310.5	6,170	7,870	1,812	1,892
" ..	0.4	0.8000	301.0	6,320	7,990	2,204	2,286
" ..	0.6	0.9000	293.5	6,480	8,090	3,084	3,040
" ..	0.8	0.9600	288.0	6,580	8,150	4,005	4,000

TABLE 3.—*Toluene-Carbon tetrachloride mixture.*

P (mm.)	N_1	N_1'	$T^\circ \text{ K.}$	L_1° cal./gm. mol.	L_2° cal./gm. mol.	$\left(\frac{\partial N_1}{\partial T}\right)_P \times 10^5$ (calc.)	$\left(\frac{\partial N_1}{\partial T}\right)_P \times 10^5$ (obs.)
100 ..	0.03	0.0300	296.5	9,175	7,750	-5,754	-6,250
„ ..	0.3	0.1040	300.2	9,112	7,700	-4,714	-4,878
„ ..	0.5	0.2100	305.0	9,050	7,662	-3,649	-3,577
„ ..	0.7	0.3990	311.5	8,975	7,575	-2,831	-2,828
150 ..	0.2	0.0650	307.9	9,012	7,625	-4,826	-5,000
„ ..	0.4	0.1600	312.5	8,950	7,562	-3,985	-3,846
„ ..	0.6	0.3160	318.0	8,875	7,512	-3,308	-3,226
„ ..	0.9	0.7380	328.5	8,725	7,385	-2,155	-2,200

TABLE 4.—*Benzene-Toluene mixture.*

P (mm.)	N_1	N_1'	$T^\circ \text{ K.}$	L_1° cal./gm. mol.	L_2° cal./gm. mol.	$\left(\frac{\partial N_1}{\partial T}\right)_P \times 10^5$ (calc.)	$\left(\frac{\partial N_1}{\partial T}\right)_P \times 10^5$ (obs.)
200 ..	0.1	0.2260	337.0	7,535	8,600	2,617	2,480
„ ..	0.3	0.5325	329.5	7,640	8,725	3,290	3,077
„ ..	0.5	0.7125	323.5	7,720	8,800	3,978	3,625
„ ..	0.7	0.8400	319.0	7,770	8,862	4,936	4,619
300 ..	0.3	0.5100	340.5	7,490	8,520	3,375	3,125
„ ..	0.4	0.6311	338.0	7,520	8,600	3,454	3,333
„ ..	0.6	0.8000	332.5	7,610	8,675	4,166	4,255
„ ..	0.7	0.8540	330.0	7,630	8,700	4,585	4,500

4. ISOTHERMAL TRANSFORMATIONS.

Equation (1) for such changes yields

$$\left(\frac{\partial P}{\partial N_1}\right)_T = \left(\frac{p_1}{N_1} - \frac{p_2}{N_2}\right) = p_1^\circ - p_2^\circ, \quad \dots \quad (3)$$

where p_1° and p_2° denote the vapour pressures of the pure components. The data of Schmidt (1926) directly give us for different temperatures the total pressure P at various concentrations of the liquid mixture and are plotted in Fig. 5 for these three systems. $(\partial P / \partial N_1)_T$ is calculated at various points on these curves and the results are given in Table 5. The agreement is indeed quite good and affords a satisfactory test of equation (3).

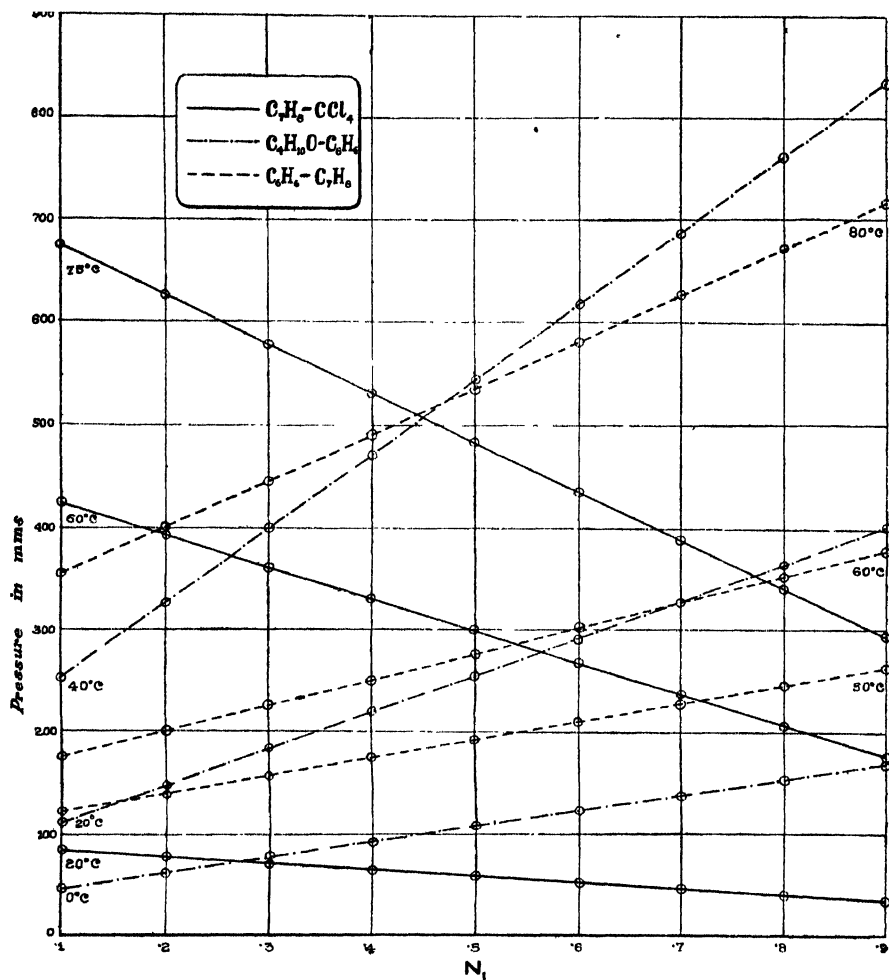


FIG. 5.

TABLE 5.

System	Temp. °K.	N_1	$\left(\frac{\partial P}{\partial N_1}\right)_T$ (cal.)	$\left(\frac{\partial P}{\partial N_1}\right)_T$ (obs.)
$C_4H_{10}O-C_6H_6$	273	0.2	160.4	160.0
" "	293	0.4	357.8	365.5
" "	313	0.6	726.0	720.0
$C_7H_8-CCl_4$	343	0.2	470.0	475.0
" "	333	0.5	307.0	310.0
" "	293	0.7	66.7	65.9
$C_6H_6-C_7H_8$	323	0.2	179.0	175.0
" "	333	0.5	249.0	257.0
" "	343	0.8	456.0	460.0

5. CHANGES AT CONSTANT COMPOSITION.

Equation (1) or I (42) for such transformations yields

$$\frac{1}{P} \left(\frac{\partial P}{\partial T} \right)_{N_1} = \frac{N_1' L_1^\circ + N_2' L_2^\circ}{RT^2} \dots \dots \dots (4)$$

Similarly equation I (41) yields

$$\frac{1}{P} \left(\frac{\partial P}{\partial T} \right)_{N_1'} = \frac{N_1 L_1^\circ + N_2 L_2^\circ}{RT^2} \dots \dots \dots (5)$$

Equation (4) refers to constant composition of liquid and equation (5) to constant composition of vapour.

Drawing tangents to the curves of Figs. 1, 2 and 3 at various points, the experimentally observed value of $(\partial P/\partial T)_{N_1}$ was found out. These are given in Table 6 together with the values of $(\partial P/\partial T)_{N_1}$ as calculated from equation (4). The agreement is seen to be quite satisfactory.

TABLE 6.

System.	N_1	$T^\circ \text{K.}$	L_1° cal./gm. mol.	L_2° cal./gm. mol.	$\left(\frac{\partial P}{\partial T} \right)_{N_1}$ (calc.)	$\left(\frac{\partial P}{\partial T} \right)_{N_1}$ (obs.)
$\text{C}_4\text{H}_{10}\text{O}-\text{C}_6\text{H}_6$	..	283	6,690	8,230	3.36	3.45
"	0.4	293	6,498	8,100	8.75	8.85
"	0.7	313	6,120	7,840	22.17	22.50
$\text{C}_7\text{H}_8-\text{CCl}_4$	..	283	9,375	7,900	2.343	2.240
"	0.6	303	9,075	7,700	4.132	4.000
"	0.8	313	8,950	7,575	3.995	4.150
$\text{C}_6\text{H}_6-\text{C}_7\text{H}_8$	..	313	7,840	8,950	3.832	4.10
"	0.5	323	7,720	8,800	7.191	7.00
"	0.8	333	7,590	8,650	20.25	21.5

Similarly from the observed data Fig. 6 is plotted giving for a few fixed temperatures the total pressures at different concentrations of the first component

TABLE 7.

System.	N_1'	N_1	Temp. ° K.	L_1° cal./gm. mol.	L_2° cal./gm. mol.	$\left(\frac{\partial P}{\partial T}\right)_{N_1'}$ (obs.)	$\left(\frac{\partial P}{\partial T}\right)_{N_1'}$ (calc.)	
$\text{C}_4\text{H}_{10}\text{O}-\text{C}_6\text{H}_6$..	0.3800	0.5000	303	6,320	8,000	7.00	6.60
„	..	0.7000	0.2800	303	6,320	8,000	11.00	10.77
„	..	0.8000	0.3812	283	6,691	8,230	7.25	6.64
$\text{C}_7\text{H}_8-\text{CCl}_4$..	0.7522	0.9000	333	8,650	7,225	6.50	6.67
„	..	0.2328	0.5000	323	8,800	7,450	8.27	8.25
„	..	0.0325	0.1000	323	8,800	7,450	10.50	11.04
$\text{C}_6\text{H}_6-\text{C}_7\text{H}_8$..	0.2021	0.1000	353	7,340	8,500	11.75	11.46
„	..	0.5113	0.3000	353	7,340	8,500	15.00	14.50
„	..	0.8361	0.7000	353	7,340	8,500	20.50	19.50

in vapour. From this $(\partial P/\partial T)_{N_1'}$ is read at different points and the values compared with those calculated from equation (5). Table 7 shows this comparison to be quite satisfactory.

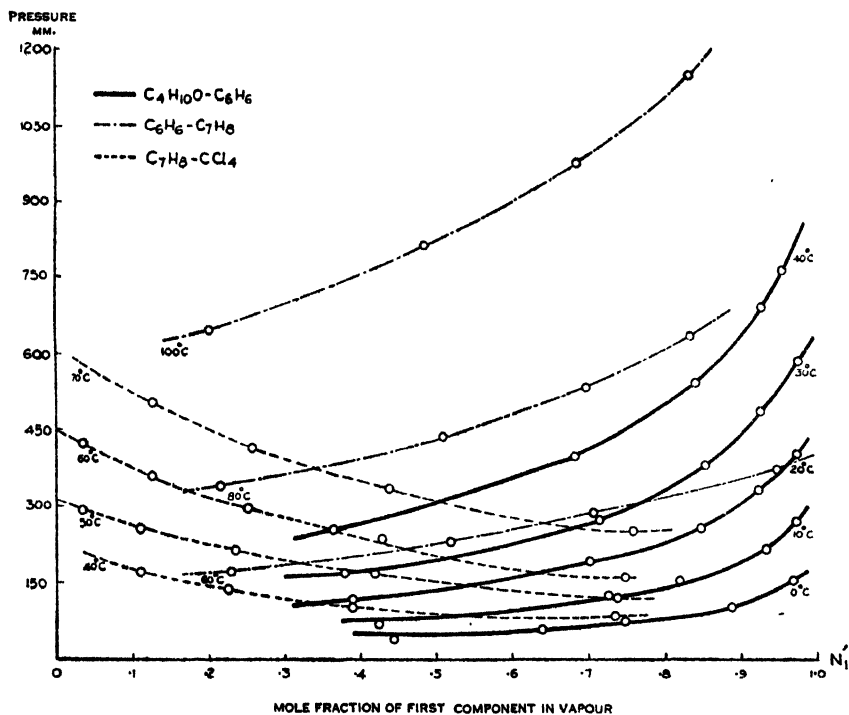


FIG. 6.

6. TERNARY MIXTURES.

Equation I (27) for the case of ideal ternary mixtures yields

$$\frac{dP}{dT} = \frac{P}{RT^2} (N_1 L_1^\circ + N_2 L_2^\circ + N_3 L_3^\circ) - P \left(\frac{N_1}{N_1'} \frac{dN_1'}{dT} + \frac{N_2}{N_2'} \frac{dN_2'}{dT} + \frac{N_3}{N_3'} \frac{dN_3'}{dT} \right) \quad (6)$$

Similarly I (32) yields

$$\begin{aligned} \frac{dP}{dT} &= \frac{P}{RT^2} (N_1' L_1^\circ + N_2' L_2^\circ + N_3' L_3^\circ) + P \left[\left(N_1' - \frac{N_1 N_3'}{N_3} \right) \times \right. \\ &\quad \left. \left(\frac{\partial \log p_1}{\partial N_1} \right)_{T,P,N_2,N_3} \frac{dN_1}{dT} + \left(N_2' - \frac{N_2 N_3'}{N_3} \right) \left(\frac{\partial \log p_2}{\partial N_2} \right)_{T,P,N_1,N_3} \frac{dN_2}{dT} \right] \\ &= \frac{P}{RT^2} (N_1' L_1^\circ + N_2' L_2^\circ + N_3' L_3^\circ) + P \left[\left(\frac{N_1'}{N_1} - \frac{N_3'}{N_3} \right) \frac{dN_1}{dT} + \left(\frac{N_2'}{N_2} - \frac{N_3'}{N_3} \right) \frac{dN_2}{dT} \right] \quad (7) \end{aligned}$$

It is easy to show that (6) and (7) are identical in the case of ideal mixtures. We therefore proceed to test equation (7). There are, however, no extensive data

on ternary systems, the observations being usually made only at one fixed total pressure. The ternary system already known to be ideal is the carbon tetrachloride-Toluene-Ethylene dibromide system for which the data are given by Schulze (1914), and Rossanoff, Schulze and Dunphy (1914). As the data refer to only one pressure (atmospheric) we can test equation (7) with regard to variations in T , N_1 and N_2 only.

Isobaric Change.—For isobaric changes equation (7) yields

$$-\frac{N_1' L_1^\circ + N_2' L_2^\circ + N_3' L_3^\circ}{RT^2} = \left(\frac{N_1'}{N_1} - \frac{N_3'}{N_3} \right) \left(\frac{\partial N_1}{\partial T} \right)_P + \left(\frac{N_2'}{N_2} - \frac{N_3'}{N_3} \right) \left(\frac{\partial N_2}{\partial T} \right)_P \quad (8)$$

This equation gives the relation between the change in temperature and the corresponding changes in the concentrations of the three components during isobaric transformations.

To test equation (8) the data of Schulze are plotted in Fig. 7 with temperature as ordinate and mole percentage as abscissa, two curves being obtained one for

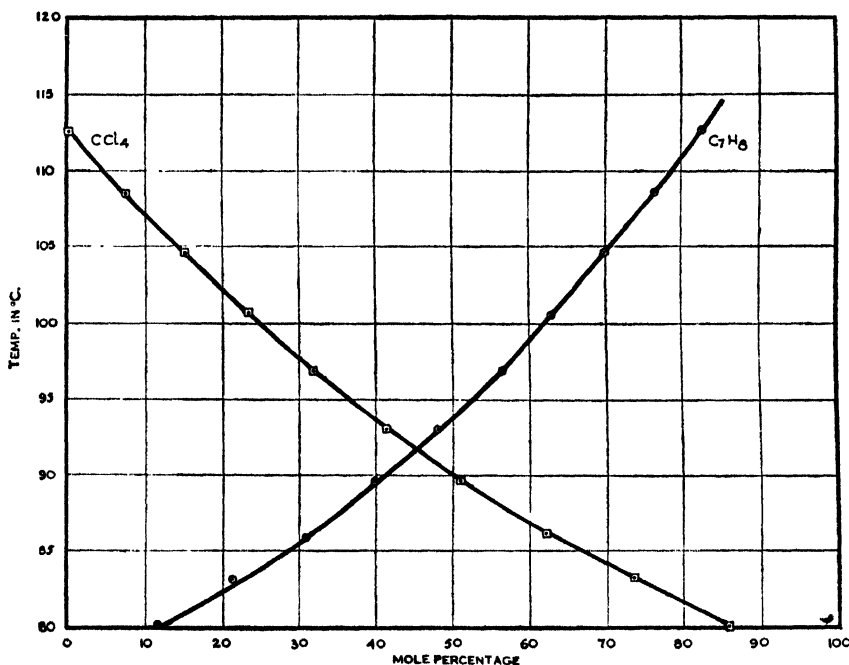


FIG. 7.

carbon tetrachloride and the other for toluene. These curves are not independent and must be read together to give the mole fractions of the two components at any desired temperature. This method of graphical representation was preferred to the usual Roozeboom method of representation as $(\partial N_1/\partial T)_P$ and $(\partial N_2/\partial T)_P$ had to be determined graphically.

From the curves $(\partial N_1/\partial T)_P$ and $(\partial N_2/\partial T)_P$ were read at various points and their corresponding values were substituted in equation (8) to give the experimentally observed value of the right-hand side of equation (8). The theoretical value of this quantity was calculated from the expression

$$-(N_1' L_1^\circ + N_2' L_2^\circ + N_3' L_3^\circ)/RT^2$$

and compared with the experimental values as shown in Table 8. The agreement is seen to be quite satisfactory and establishes the validity of equation (8) and simultaneously proves that the system is ideal.

TABLE 8.

Temp. °C.	N_1 (CCl_4)	N_2 (C_7H_8)	L_1° cal./gm. mol.	L_2° cal./gm. mol.	L_3° cal./gm. mol.	$\frac{N_1'L_1^\circ + N_2'L_2^\circ + N_3'L_3^\circ}{RT^2} \times 10^5$	$\frac{(N_2'/N_3 - N_1'/N_1)(\partial N_1/\partial T)_P}{(N_2'/N_3 - N_2'/N_2)(\partial N_2/\partial T)_P} \times 10^5$
90	0.5000	0.4200	7,000	8,250	9,085	2,780	2,881
95	0.3650	0.5350	6,950	8,175	9,035	2,780	2,820
100	0.2500	0.6200	6,900	8,100	8,985	2,713	2,760
105	0.1450	0.7080	6,850	8,050	8,935	2,654	2,782
110	0.0500	0.7850	6,800	7,975	8,885	2,696	2,601

Isobaric changes with constant concentration of one component.—Equation (8) for this case yields

$$\left(\frac{\partial N_1}{\partial T}\right)_{P, N_2} = -\frac{N_1'L_1^\circ + N_2'L_2^\circ + N_3'L_3^\circ}{RT^2} \left/ \left(\frac{N_1'}{N_1} - \frac{N_3'}{N_3}\right) \right. \quad \dots (9)$$

$$\left(\frac{\partial N_2}{\partial T}\right)_{P, N_1} = -\frac{N_1'L_1^\circ + N_2'L_2^\circ + N_3'L_3^\circ}{RT^2} \left/ \left(\frac{N_2'}{N_2} - \frac{N_3'}{N_3}\right) \right. \quad \dots (10)$$

For verifying equations (9) and (10) the data of Rosanoff, Schulze and Dunphy (1914) are plotted in Fig. 8 for a few fixed temperatures, the abscissa being the mole percentage of ethylene dibromide and the ordinate the mole percentage of toluene. For constant concentration N_2 of toluene a straight line parallel to the x -axis was drawn and the corresponding ΔN_1 (change in concentration of ethylene dibromide)* and ΔT were read from the graph. This ratio of $(\Delta N_1/\Delta T)_{P, N_2}$ is compared with the theoretical value obtained from equation (9) for $(\partial N_1/\partial T)_{P, N_2}$. The results are given in Table 9.

Similarly the ratio $(\Delta N_2/\Delta T)_{P, N_1}$ for the change of concentration of toluene with temperature at constant concentration of ethylene dibromide was read from the graph, and the theoretical values were calculated from equation (10) and are recorded in Table 9. The agreement in both the cases is quite satisfactory.

Isothermal-isobaric changes.—Equation (8) for this case yields

$$\left(\frac{\partial N_1}{\partial N_2}\right)_{P, T} = -\left(\frac{N_2' - N_3'}{N_2 - N_3}\right) \left/ \left(\frac{N_1'}{N_1} - \frac{N_3'}{N_3}\right) \right. \quad \dots \quad \dots (11)$$

$$= -(p_2^\circ - p_3^\circ)/(p_1^\circ - p_3^\circ). \quad \dots \quad \dots \quad \dots (12)$$

*In the discussion hereafter the suffix 1 denotes ethylene dibromide and the suffix 3 denotes carbon tetrachloride, while in the previous discussion the reverse was the case.

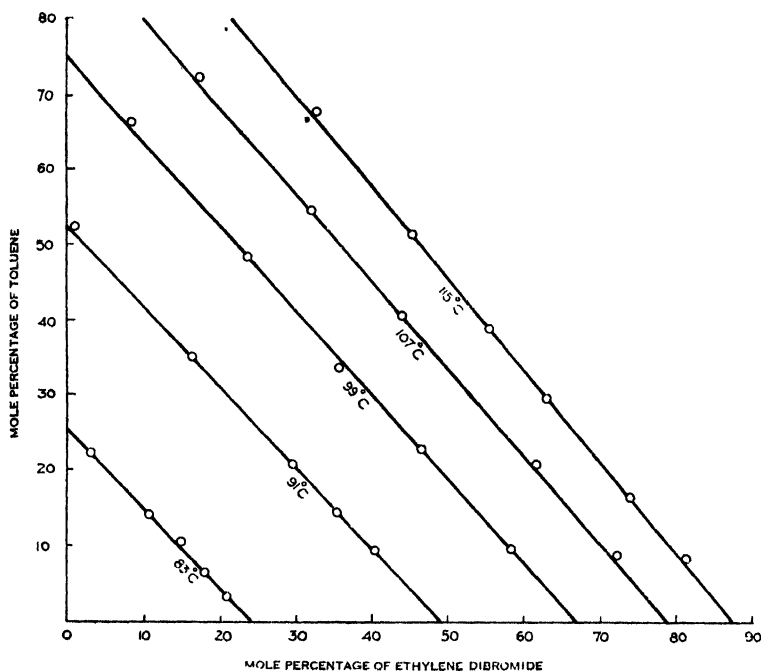


FIG. 8.

TABLE 9.

Temp. °C.	N_1 $C_2H_4Br_2$	N_2 C_7H_8	L_1° cal./gm. mol.	L_2° cal./gm. mol.	L_3° cal./gm. mol.	$\left(\frac{\partial N_1}{\partial T}\right)_{P, N_2} \times 10^5$ (obs.)	$\left(\frac{\partial N_1}{\partial T}\right)_{P, N_2} \times 10^5$ (calc.)	$\left(\frac{\partial N_2}{\partial T}\right)_{P, N_1} \times 10^5$ (obs.)	$\left(\frac{\partial N_2}{\partial T}\right)_{P, N_1} \times 10^5$ (calc.)
99	0.10	0.63	8,995	8,125	6,875	2,000	1,820	2,455	2,345
107	0.30	0.57	8,915	8,000	6,800	1,509	1,595	1,840	1,895
107	0.40	0.45	8,915	8,000	6,800	1,503	1,593	1,820	1,892

Fig. 8 enables us to verify equations (11) and (12). The results are given in Table 10.

TABLE 10.

Temp. °C.	N_1 ($C_2H_4Br_2$)	N_2 (C_7H_8)	N_1'	N_2'	$\left(\frac{\partial N_1}{\partial N_2}\right)_{P, T}$ (obs.)	$\left(\frac{\partial N_1}{\partial N_2}\right)_{P, T}$ (calc.)
83	0.0331	0.2202	0.0150	0.1010	-0.934	-0.973
91	0.0091	0.5222	0.0004	0.3080	-1.072	-1.166
99	0.5812	0.0953	0.2460	0.0690	-1.113	-1.087
107	0.1745	0.7181	0.1020	0.6540	-1.157	-1.232
115	0.7397	0.1628	0.4720	0.1920	-1.231	-1.240

Our thanks are due to Professor A. C. Chatterji for his keen interest in the progress of the work.

SUMMARY.

The modified Clausius-Clapeyron relation deduced in a previous paper by the present authors for the thermodynamic equilibrium of a system of any number of components existing in the vapour and condensed phases has been applied to several ideal liquid mixtures. The relations deduced there between pressure, temperature and concentrations and their variations have been shown to be accurately obeyed by the binary mixtures ether-benzene, toluene-carbon tetrachloride and benzene-toluene. Various particular cases have also been tested. For the ternary system carbon tetrachloride-toluene-ethylene dibromide also, these formulae have been found to hold equally well and the effects of the variation of concentrations of the various components have been quantitatively discussed and shown to agree with theoretically predicted values.

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NOTE ON TARGET PENETRATION BY ROTATING CHARGES WITH LINED CONICAL CAVITIES

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1. INTRODUCTION.

High explosive charges with metal-lined conical cavities (Shaped Charges) have received considerable attention in the last decade because of their usefulness in making holes through thick armour plate or producing deep penetration into other materials. The hydrodynamic theories of jet formation and target penetration by such charges have been published by Birkhoff, MacDougall, Pugh and Taylor (1948). By an extension of the steady-state hydrodynamic theory, Pugh, Eichelberger and Rostoker (1952) have explained the formation of the entire jet (including the 'after jet') and the velocity gradient in the jet. It is well known that when a shaped charge rotates about its axis, there is a loss of penetration (Loosbrock, 1950). Basset and Basset (1950) have stated that the penetration by a rotating charge diminishes rapidly with increasing speed of rotation and have attributed it to the pressure produced by centrifugal force.

The object of the theoretical work described in this note is to explain the loss of penetration due to rotation of a shaped charge on the basis that when such an equipment rotates, it imparts an angular velocity to the jet resulting in the increase of its cross-sectional area. A relation is given connecting penetration and speed of rotation. The effect of standoff on the performance of a rotating shaped charge and the profiles of holes at different rotations are also discussed.

2. DEPTH OF PENETRATION.

Let us imagine a variable jet (a jet along which velocity gradient exists) to be divided into small elements each having a definite velocity. When a shaped charge rotates about its axis, we may assume that it imparts an angular velocity to an element of the jet, which is responsible for its spreading (i.e. the increase of its cross-sectional area), and the spreading is symmetrical about the axis. Let r_0 represent the radius of an element of the jet (when it just starts spreading) and r be the radius at any time τ . We assume that r is given by the expression

$$r = r_0 + \epsilon v \tau \quad \dots \quad (1)$$

where v is the 'tangential' velocity (see below) of that element in the jet and ϵ is a constant. Let ω and Ω represent the angular velocities of an element in the liner and the corresponding element in the jet respectively and let Z be the perpendicular distance of the small element in the original conical liner on its axis, i.e. its radius. Equating the angular momentum of a finite element on the surface of liner to that of the corresponding element in the jet, we have

$$\omega Z^2 = \Omega r_0^2 \quad \dots \quad (2)$$

The tangential velocity of the element in the jet is given by

$$v = \Omega r_0 = \frac{\omega}{r_0} Z^2 \quad \dots \quad (3)$$

and substituting the value of v from eq. (3) in eq. (1), we have

$$r = r_0 \left[1 + \epsilon \frac{\omega}{r_0^2} \tau Z^2 \right] \quad \dots \quad (4)$$

This indicates that as the angular velocity of an element in the liner increases, the radius of the corresponding element in the jet at any time τ also increases.

In a previous paper (Singh, 1953), the penetration by non-rotating charges has been discussed. Let ΔL represent the length of an element of the jet that is just formed from a finite element in the slant surface of the liner. The element ΔL of the jet starts to move along the axis of the equipment, draws out like a ductile metal and becomes narrower till its length is $C\Delta L$, where C is a constant. Further lengthening of the jet causes it to break into particles. Let dL represent the length of the element of the jet when it is about to strike a target. The penetration dP in a target by the element dL of the jet is given by the expression

$$dP = dL \sqrt{\frac{\lambda \rho_j}{\rho_T}} (1 - kR) \quad \dots \quad (5)$$

where $\lambda \rho_j$ is the effective density of the element of the jet, ρ_T is the density of the target and R is the work per unit volume required to form a deep hole in an infinite block (as usual, for materials which do not harden appreciably and for annealed metals, R is of the order of 3.5 to 4 times and 5 to 6 times the initial yield stress respectively). k is given by the expression

$$k = \left(\frac{1}{V\sqrt{\lambda \rho_j}} + \frac{1}{V\sqrt{\rho_T}} \right)^2 \quad \dots \quad (6)$$

where V is the mean velocity of the jet element.

The penetration by rotating shaped charges has been discussed under two cases—Case 1: $dL < C\Delta L$; Case 2: $dL > C\Delta L$ —and both may occur at different times in the same element of the jet.

Case 1.—Let ρ represent the density of the metal in the original conical liner. The relative small compressibility of the metal in the liner is neglected and it is assumed that the density of the jet element ΔL is also ρ . As ΔL elongates to $C\Delta L$ (ductile drawing) so the density of $C\Delta L$ is also ρ . When a shaped charge rotates, the different elements in the jet have different angular velocities and it may be expected that the increase of the angular velocity of a jet element may decrease the extent of ductile drawing. In the absence of any experimental data, it may be assumed that the ductile drawing is the same for different elements of a jet and the spreading of different elements of the jet due to rotation is negligible as long as ductile drawing continues. The value of C for rotating charges is the same as for non-rotating charges. The primary penetration dP by an element dL of the jet is given by the expression

$$dP = dL \sqrt{\frac{\rho}{\rho_T}} (1 - kR) \quad \dots \quad (7a)$$

If the liner and the target are of the same metal ($\rho = \rho_T$), the above equation reduces to

$$dP = dL \left(1 - \frac{4R}{V^2 \rho_T} \right) \quad \dots \quad (7b)$$

The parameters dL and V of an element of the jet are known, hence for a given target the depth of primary penetration dP can be evaluated.

Case 2.—If the lengthening of ΔL element of the jet continues beyond $C\Delta L$, then it breaks up into particles. Due to the angular velocity in an element of the jet it starts spreading. Obviously r_0 represents the radius of the jet element when its length is $C\Delta L$ and r its radius when its length is dL . Let dm_j represent the mass of metal in the element of the jet. Since the same mass dm_j is contained in $C\Delta L$ and dL elements of the jet, we have

$$dm_j = \pi r_0^2 C\Delta L \rho = \pi r^2 dL \lambda \rho_j \quad \dots \quad (8)$$

$$\sqrt{\lambda \rho_j} = \sqrt{\frac{C\Delta L \rho}{dL}} \frac{r_0}{r} \quad \dots \quad (9)$$

Substituting the value of r from eq. (4) and the value of r_0 from eq. (8) in eq. (9), we have

$$\sqrt{\lambda \rho_j} = \sqrt{\frac{C\Delta L \rho}{dL}} \frac{dm_j}{dm_j + \pi \epsilon \omega Z^2 C\Delta L \rho \tau} \quad \dots \quad (10)$$

As τ is the time taken by $C\Delta L$ element of the jet to elongate to dL , hence

$$\tau = \frac{dL - C\Delta L}{V_j - V'_j} \quad \dots \quad (11)$$

where V_j and V'_j are the velocities of the head and the tail end of the element of the jet respectively. Substituting the above value of τ in eq. (10), we have

$$\sqrt{\lambda \rho_j} = \sqrt{\frac{C\Delta L \rho}{dL}} \frac{dm_j}{dm_j + \pi \epsilon \omega Z^2 C\Delta L \rho \left(\frac{dL - C\Delta L}{V_j - V'_j} \right)} \quad \dots \quad (12)$$

Putting

$$\sigma = \pi Z^2 C\Delta L \rho \left(\frac{dL - C\Delta L}{V_j - V'_j} \right) \quad \dots \quad (13)$$

in eq. (12), we have

$$\sqrt{\lambda \rho_j} = \sqrt{\frac{C\Delta L \rho}{dL}} \frac{dm_j}{dm_j + \epsilon \sigma \omega} \quad \dots \quad (14)$$

The factor $dm_j/(dm_j + \epsilon \sigma \omega)$ is non-dimensional. Substituting the value of $\lambda \rho_j$ from eq. (14) in eq. (6) we have

$$k = \frac{1}{V^2 \rho_T} \left[\sqrt{\frac{dL \rho_T}{C\Delta L \rho}} \frac{dm_j + \epsilon \sigma \omega}{dm_j} + 1 \right]^2 \quad \dots \quad (15)$$

Substituting the values of $\lambda \rho_j$ and k from eqs. (14) and (15) in eq. (5), we have

$$dP = \sqrt{\frac{C\Delta L dL \rho}{\rho_T}} \frac{dm_j}{dm_j + \epsilon \sigma \omega} \left[1 - \frac{R}{V^2 \rho_T} \left(\sqrt{\frac{dL \rho_T}{C\Delta L \rho}} \frac{dm_j + \epsilon \sigma \omega}{dm_j} + 1 \right)^2 \right] \quad (16)$$

The eqs. (14) and (15) indicate that as ω increases, the effective density of a jet element and the factor $(1 - kR)$ decrease; hence the primary penetration by an element of a jet also decreases. As Z progressively increases from the apex to the base of a liner, so for a given rotation of a shaped charge, the deleterious effect of rotation on penetration increases from the head to the tail end of the jet. In eq. (16), the parameters dm_j , ΔL , dL and R for any element of the jet can be evaluated

while the constants C and ϵ are unknown. C represents the ductile drawing and its value for rotating charges is assumed to be the same as for non-rotating charges. The value of ϵ is so chosen that the theoretical curve of 'penetration-angular velocity' gives an overall fit with the experimental curve. The primary penetration by an element of the jet can be evaluated by eq. (7a) or (16) depending on whether $dL < C\Delta L$ or $dL > C\Delta L$, respectively. The method of calculating the total primary penetration is the same as discussed by the author in an earlier paper (1953). This takes into account the effects of the velocity gradient in the jet, the standoff distance and strength of the target.

3. A TYPICAL EXAMPLE TO ILLUSTRATE THE METHOD OF CALCULATIONS.

Let V_0 represent the velocity of collapse, β the angle which the collapsing element makes with the axis of the equipment and x the distance from the apex along the axis to the plane of the zonal element in the slant surface of the conical liner. Eichelberger and Pugh (1952) have published the curves of V_j , V_0 and β as functions of x for a 44° steel conical liner and these values* are taken as the basis of calculations. Let D be defined as the calibre of the equipment, which in this case is $1\frac{1}{8}$ ". For evaluating the primary penetration, the value of velocity of detonation U_d , density of liner metal, density of target material and R are taken as 0.751 cm./ μ sec., 7.8 gm./c.c., 7.8 gm./c.c. and 1.32×10^{10} dynes/cm.² respectively. The calculated total primary penetration at $1\frac{1}{2}D$ standoff as a function of the angular velocity is given in Table I.

TABLE I.

Calculated primary penetration as a function of the angular velocity of the shaped charge.

Rev. per sec.	Total primary penetration (cm.)	
	$C = 2.0$ $\epsilon = 1.0$	$C = 1.7$ $\epsilon = 1.0$
0	11.13	10.24
50	7.51	7.08
100	5.98	5.64
160	5.17	4.84
200	4.85	4.52

The plot of primary penetration as a function of the speed of rotation is shown in Fig. 1.

The measurement of the extent of ductile drawing in an element of the jet, formed from a rotating shaped charge, even when possible, is a difficult experimental task. As an extreme case it is assumed that at the high angular velocities of the liner, the ductile drawing in different elements of the jet is absent ($C = 1$), i.e. as soon as ΔL length of an element of the jet is formed it breaks up into fragments. The primary penetration by an element of the jet can be evaluated by eq. (16), in which C is equal to unity and ϵ is an unknown parameter. From the best overall fit of the experimental and the theoretical 'penetration-angular velocity' curves, a suitable value of ϵ can be chosen. The calculated total primary penetration at

* The collapse parameters for the given conical liner have been supplied by Prof. E. M. Pugh or which the author is grateful.

$1\frac{1}{2}D$ standoff as a function of the angular velocity (taking ϵ to be equal to 1.0 and 0.5) is given in Table II.

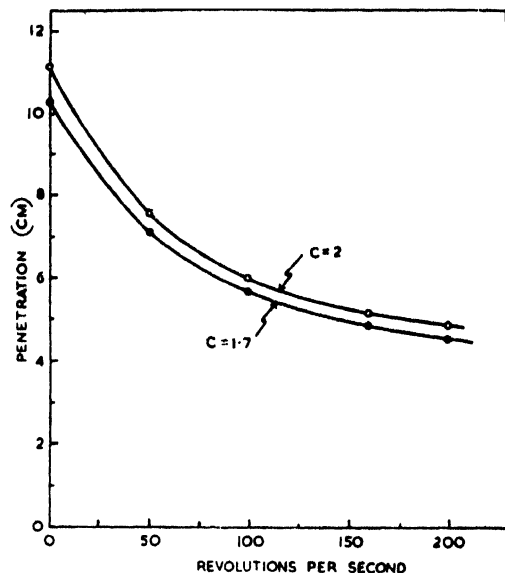


FIG. 1. Calculated correlation of penetration and speed of rotation ($\epsilon = 1$).

TABLE II.

Calculated primary penetration as a function of the angular velocity of the shaped charge.

Rev. per sec.	Total primary penetration (cm.)	
	$C = 1.0$ $\epsilon = 1.0$	$C = 1.0$ $\epsilon = 0.5$
100	4.46	5.57
160	3.66	4.84
200	3.36	4.46
320	2.70	3.66

The plot of primary penetration (assuming that ductile drawing in different elements of the jet is absent) as a function of the speed of rotation is shown in Fig. 2. Figs. 1 and 2 indicate that for the given equipment the penetration diminishes rapidly as the speed of rotation increases from static to 100 rev. per sec. (R.P.S.). The decrease of penetration is very gradual as the speed of rotation increases beyond 100 R.P.S. Basset and Basset (1950) have stated that penetration by a shaped charge diminishes rapidly with increasing speed of rotation but they have not published the experimental or theoretically calculated results.

To study the effect of standoff on the performance of rotating shaped charges, the total primary penetrations at different standoffs are calculated (taking C and ϵ to be equal to 2 and 1 respectively) and the results are tabulated in Table III.

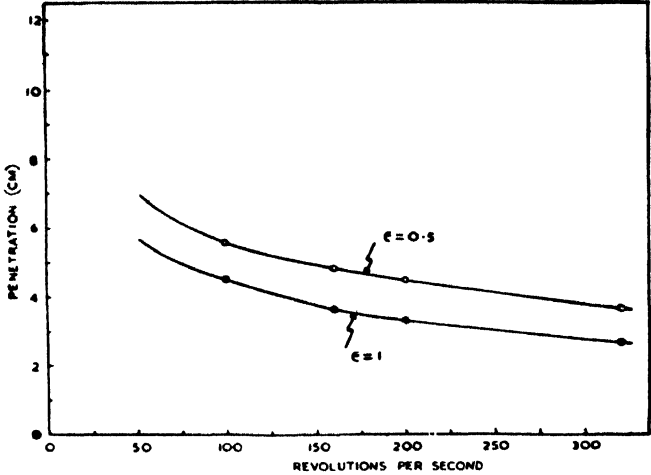


FIG. 2. Calculated correlation of penetration and speed of rotation ($C = 1$).

TABLE III.
Calculated primary penetration by the rotating charge (160 R.P.S.) as a function of standoff.

Standoff (in units of calibre)	Total penetration (cm.)
$\frac{3}{2}D$	5.88
$1\frac{1}{2}D$	5.17
$2\frac{1}{2}D$	4.70

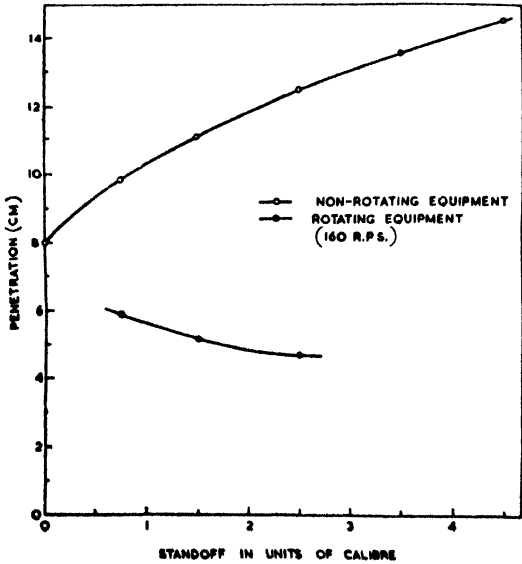


FIG. 3. Calculated correlation of penetration and standoff of non-rotating and rotating shaped charges,

The plot of primary penetration (taking C and ϵ to be equal to 2 and 1 respectively) as a function of standoff is shown in Fig. 3 (for comparison a similar curve for non-rotating charge is also shown in the same figure). This indicates that the deleterious effect of rotation increases with the increase of standoff. At $2\frac{1}{2}D$ standoff, the tail end of the jet is responsible for too less a penetration and as such the performance of rotating charges at such standoffs will be erratic.

The calculated profiles of holes at $1\frac{1}{2}D$ standoff by the non-rotating and the rotating charges (100 R.P.S. and 160 R.P.S.) are shown in Fig. 4. This indicates that the radius near the bottom of the hole goes on becoming broader with increase of the speed of rotation of a shaped charge. Pack and Evans (1951) have stated that the increment in penetration due to the free 'after-flow' of the target (secondary penetration) is approximately equal to the radius of the hole (measured near the bottom of hole) made by the jet. Hence it is expected that the secondary penetration will go on increasing with the increase of revolutions of a shaped charge equipment.

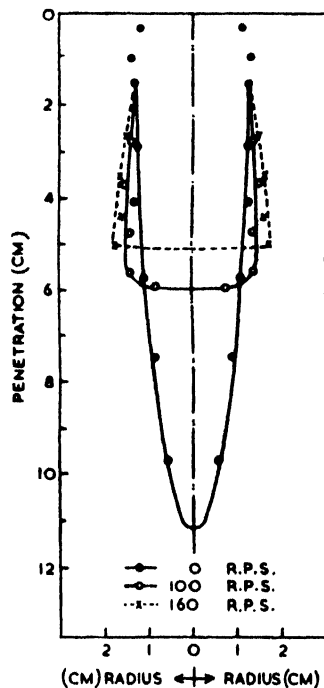


FIG. 4. Calculated profiles of hole of a non-rotating and rotating shaped charges.

4. CONCLUSIONS.

The theoretical discussions indicate that (i) the primary penetration by rotating charges (at about 10,000 revolutions per minute) with lined conical cavities is about 50% of its static performance, (ii) the deleterious effect of a given rotation on primary penetration progressively increases from the head to the tail end of the jet, (iii) the loss of primary penetration at a given speed of rotation of the conical liner is less at low standoffs, (iv) the volume of the hole remains approximately the same whether the equipment is non-rotating or it is rotating at different revolutions, (v) the bottom of the hole goes on becoming broader and the secondary penetration goes on increasing with increase of the speed of rotation of a shaped charge.

ACKNOWLEDGEMENTS.

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ABSTRACT.

The hydrodynamic theories of jet formation and target penetration by explosives with metal-lined conical cavities have been published by Birkhoff, MacDougall, Pugh and Taylor (1948) and Pugh, Eichelberger and Rostoker (1952). When such an equipment rotates, its penetration in a target is considerably reduced. In this note, a theoretical explanation of the loss of penetration due to rotation is proposed on the basis that when such an equipment rotates, it imparts an angular velocity to the jet resulting in the increase of its cross-sectional area. A relation is given connecting penetration and speed of rotation taking into account the velocity gradient in the jet, the standoff distance and strength of the target.

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THE MODE OF ACTION OF AUREOMYCIN HYDROCHLORIDE ON *ENTAMOEBA HISTOLYTICA* IN VITRO

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For evaluating the action of aureomycin hydrochloride, particularly in amoebic infections of the intestine, extensive trials have been given on patients suffering from this disease. On the basis of such clinical trials, it has been claimed that aureomycin is the least toxic and the most effective anti-amoebic drug known. Only a few studies *in vitro* have so far been made. After noting the E_h values of cultures of *Entamoeba histolytica*, Bradin and Hansen (1950) concluded that aureomycin was primarily effective against the associated bacteria. During the course of screening anti-amoebic drugs Hewitt *et al.* (1950) adopted a procedure somewhat different from that which is commonly used. Their work suggests that aureomycin exerts direct lethal action on the trophozoites of the strain of *E. histolytica* used by them.

In order to determine the effects of aureomycin on amoebae, the present investigations were undertaken and in all these experiments *E. histolytica* (strain No. 7) was used. The method No. 2 as described by Hewitt and his co-workers (1950), after some modifications, was employed. Along with aureomycin the action of emetine hydrochloride was also studied.

EXPERIMENTAL.

As the crystalline variety was not available, solution of aureomycin hydrochloride ranging from 1 : 100 to 1 : 8,000 were prepared in normal saline from the powder. Washed sediments from 48 hours' old cultures, containing motile trophozoites, were used. After the final washing the sediment was suspended in about 5 c.c. of aureomycin solution of desired strength and incubated at 37°C. At intervals of half an hour samples from the suspension containing trophozoites, starch and bacteria were washed with normal saline several times to remove the aureomycin. The washed trophozoites were then inoculated in fresh E_3 media* with addition of an emulsion of fresh cultures of bacteria from strains Nos. 1, 2 and 3 †. The seeded tubes were incubated at 37°C. and examined after 48, 72, 96, 120, 144 and 168 hours as shown in the accompanying tables. The action of aureomycin on the associated bacteria present in the washed sediment was also studied in nutrient broth.

The effects of 1 : 8,000; 1 : 4,000; 1 : 2,000; 1 : 1,000; 1 : 500 and 1 : 100 solutions of aureomycin hydrochloride on the growth of the amoebae are shown in Tables I, II, III, IV, V and VI. The length of contact between aureomycin and amoebae is also noted in the tables.

* E_3 medium: its composition will be published in a later paper.

† Strains 1, 2 and 3: these are stock cultures of bacteria growing in association with *E. histolytica* strain No. 7.

TABLE I
(showing the effects of 1 : 8,000 aureomycin on E. histolytica).

Tube No.	Medium.	Contact with aureomycin.	Growth after					
			48 hrs.	72 hrs.	96 hrs.	120 hrs.	144 hrs.	168 hrs.
381	E_3	$\frac{1}{2}$ hour	+ /2	+	+	+	+	+
382	E_3	1 hour	+ /2	+	+	+	+	+
383	E_3	1 $\frac{1}{2}$ hours	+ /2	+	+	+	+	+

+ /2 indicates 5 or less than 5 trophozoites per field as observed under low power.

TABLE II
(showing the effects of 1 : 4,000 aureomycin on E. histolytica).

Tube No.	Medium.	Contact with aureomycin.	Growth after					
			48 hrs.	72 hrs.	96 hrs.	120 hrs.	144 hrs.	168 hrs.
378	E_3	$\frac{1}{2}$ hour	*	++	+++	+++	+++	+
379	E_3	1 hour	*	++	+++	+++	+++	+
380	E_3	1½ hours	*	+	+++	+++	+++	+

* The number of trophozoites were scanty, one or two only being found after a prolonged search under low power. This indicates absence of multiplication of the amoebae.

TABLE III
(showing the effects of 1 : 2,000 aureomycin on *E. histolytica*).

Tube No.	Medium.	Contact with aureomycin.	Growth after					
			48 hrs.	72 hrs.	96 hrs.	120 hrs.	144 hrs.	168 hrs.
361	E ₃	$\frac{1}{2}$ hour	*	+	+	+	+	+ ²
362	E ₃	1 hour	*	+	+	+	+	+ ²
363	E ₃	1 $\frac{1}{2}$ hours	*	+	+	+	+	+
364	E ₃	2 hours	*	+	+	+	+	+
365	E ₃	2 $\frac{1}{2}$ hours	*	+	+	+	+	+
366	E ₃	3 hours	Nil	+	+	+	+	+
367	E ₃	3 $\frac{1}{2}$ hours	Nil	+	+	+	+	+
368(a)	E ₃	4 hrs. in saline	+	+	+	+	+	+
368(b)	E ₃	6 hrs. in saline	..	..	..	..	..	..

TABLE IV
(showing the effects of 1 : 1,000 aureomycin on *E. histolytica*).

Tube No.	Medium.	Contact with aureomycin.	Growth after				
			48 hrs.	72 hrs.	96 hrs.	120 hrs.	144 hrs.
413	E ₃	1 hour	*	+	+	+	+
414	E ₃	2 hours	*	+	+	+	+
415§	E ₃	1 hour	*	+	+	+	+
416§	E ₃	2 hours	*	+	+	+	+

* The number of trophozoites were scanty, one or two only being found after a prolonged search under low power. This indicates absence of multiplication of the amoebae.

§ Indicates the tube in which the bacterial emulsion was not added.

TABLE V
(showing the effects of 1 : 500 aureomycin on *E. histolytica*).

Tube No.	Medium.	Contact with aureomycin.	Growth after							
			48 hrs.	72 hrs.	96 hrs.	120 hrs.	144 hrs.	168 hrs.	192 hrs.	
403	E_3	$\frac{1}{2}$ hour	*	+	+	+	+	+	+	+
404	E_3	1 hour	*	+	+	+	+	+	+	+
405	E_3	$1\frac{1}{4}$ hours	*	+	+	+	+	+	+	+
406	E_3	$\frac{1}{2}$ hours	*	+	+	+	+	+	+	+

TABLE VI
(showing the effects of 1 : 100 aureomycin on *E. histolytica*).

Tube No.	Medium.	Contact with aureomycin.	Growth after						
			48 hrs.	72 hrs.	96 hrs.	120 hrs.	144 hrs.	168 hrs.	192 hrs.
452	E ₃	$\frac{1}{4}$ hour	*	+	+	+	+	+	+
453	E ₃	1 hour	Nil	*	+	+	+	+	+
454	E ₃	2 hours	Nil	Nil	+	+	+	+	+
455	E ₃	3 hours	Nil	Nil	Nil	+	+	+	+
</									

* The number of trophozoites were scanty, one or two only being found after a prolonged search under low power. This indicates absence of multiplication of the amoebae.

The tables show that:

- (a) With 1 : 8,000 solution of aureomycin acting for $1\frac{1}{2}$ hours, its action on the growth of the amoebae was not marked.
- (b) With 1 : 4,000 to 1 : 500 solutions and with a length of contact extending up to $3\frac{1}{2}$ hours, there was no growth up to 48 hours, feeble at 72 hours but the growth appreciably increased thereafter.
- (c) With 1 : 100 solution of aureomycin several observations were made by varying the length of contact. These are:
 - (i) with length of contact up to $\frac{1}{2}$ hour: No growth up to 48 hours, feeble growth at 72 hours, profuse growth thereafter;
 - (ii) with length of contact up to 2 hours: No growth up to 72 hours, feeble growth at 96 hours, and profuse growth thereafter;
 - (iii) with length of contact up to 3 hours: No growth up to 96 hours, profuse growth thereafter.
- (d) The viability of the trophozoites treated with aureomycin was always increased.

There was no inhibition of the growth of the accompanying bacteria as a result of the action of aureomycin.

Effect of emetine hydrochloride on the growth of E. histolytica:

This was studied by using 1 : 500 emetine hydrochloride solution and extending the length of contact between emetine solution and trophozoites to 4 hours. The results are noted in Table VII.

TABLE VII

(showing the effects of 1 : 500 emetine hydrochloride on *E. histolytica*).

Tube No.	Medium.	Contact with emetine.	Growth after			
			48 hrs.	72 hrs.	96 hrs.	120 hrs.
482	E_3	$\frac{1}{2}$ hour	++++	+++++	+++	+ / 2
483	E_3	$1\frac{1}{2}$ hours	++++	+++++	+++	+ / 2
484	E_3	2 hours	+ + + + +	+ + + + +	++	Nil
485	E_3	3 hours	++	+ + + + +	+++	+ / 2
486	E_3	4 hours	++	+ + + + +	+ + + +	Nil

The above indicates that emetine hydrochloride in a strength of 1 : 500 when allowed to act for 4 hours did not produce any inhibition of the growth of the amoebae. In this connection it is to be noted that in most of the tubes culturing the trophozoites after treatment with emetine, though the growth was profuse yet there were several large sized amoebae which were detected after 48 hours' incubation. The latter were sluggishly motile and 3 to 4 times larger than normal trophozoites; they also showed presence of starch particles in the cytoplasm. However, from the granular nature of the cytoplasm, they were regarded as being degenerative forms. These giant trophozoites disappeared after a few serial sub-cultures.

DISCUSSION.

In screening anti-amoebic drugs two methods are generally employed. These are: (1) After addition of the drug directly to the fluid overlay of a culture medium before inoculation of the trophozoites, the growth of the amoebae after 48 hours' incubation at 37°C. is observed, and (2) Inoculation of fresh media after suspension of the trophozoites in an aqueous solution of the drug followed by repeated washing in normal saline. The concentration of the drug in solution and the length of contact between the trophozoites and the drug are varied according to requirements; observations are made after 48 hours' incubation at 37°C. and also thereafter.

It has already been demonstrated (Mukherjea, 1951:35), that bacteriostatic substances such as streptomycin, sulfadiazine, etc. when added to a culture medium growing *E. histolytica* with bacteria, in sufficiently large doses, inhibit the growth of the amoebae. The inhibition, under such circumstances, is due to suppression of the bacterial metabolism, since clinical trials of these drugs have not succeeded in curing amoebic infections. They are thus indirect amoebicides (*in vitro*). The use of method No. (1) in testing the anti-amoebic action of a drug having bacteriostatic properties at the same time is thus likely to give incorrect results.

The second method aims at screening out those that are directly amoebicidal. In our experiments, in order to eliminate the toxic products of metabolism of amoebae and bacteria, yet unpublished, the sediment was washed in several changes of normal salt solution. Aureomycin solution was then mixed with the sediment. The elimination of toxic metabolites of bacteria and amoebae is essential as these may interfere with the action of aureomycin on amoebae. It should be noted that in this method the contact between the trophozoites and the drug should not be unduly prolonged. Even in normal salt solution the trophozoites seldom survive longer than 6 to 8 hours. Hence the length of contact between aureomycin and the amoebae is vitally important in assessing the action of every amoebicidal drug on trophozoites. Under these circumstances any favourable effects of a drug can only be judged from the degeneration or inhibition of growth of the amoebae taking place as a result of contact maintained up to this time limit.

Aureomycin in dilution of 1 : 8,000 did not appear to produce any action on the trophozoites of *E. histolytica* (vide Table I), but with dilutions ranging from 1 : 4,000 to 1 : 500 and with a maximum length of contact of 3½ hours, the growth and multiplication were inhibited up to 48 hours (vide Tables II, III, IV and V). The inhibitory effects of aureomycin on multiplication of the amoebae were particularly evident when a 1 : 100 solution of the antibiotic was used and the contact with the trophozoites was maintained up to a maximum of 3 hours (vide Table VI). There was no growth up to 72 hours when the length of contact was 2 hours, but when it was extended to 3 hours, the amoebae remained inactive up to 96 hours. In every experiment, however, the growth was profuse and viability increased as soon as the temporary inhibitory effects of aureomycin on the amoebae passed off. The above observations indicate that aureomycin is not directly lethal to the trophozoites of *E. histolytica* of the strain used in these experiments but it can only suppress their reproductive activity temporarily. The duration of inhibition of multiplication has a direct bearing on the concentration of the drug used and the length of contact with the amoebae.

From the results noted in Table VII, it is apparent that emetine hydrochloride in 1 : 500 solution does neither kill the amoebae nor inhibit their reproduction within four hours. The degeneration of trophozoites, noticed after treatment with emetine was an indication that it was due to emetine. The action of a drug depends not only on the concentration but also on the length of contact. It cannot, however, be expected that all amoebicidal drugs would exercise their maximum effects on trophozoites within 4 hours. It is probable that with 1 : 500 solution of emetine,

only the highly susceptible individuals would be affected in course of four hours as was noticed in our observations. Some might have died, some appeared to have undergone degeneration though still living, whereas the comparatively resistant trophozoites escaped and multiplied in the normal manner.

Degenerated trophozoites were never seen in culture media inoculated with trophozoites treated with aureomycin. This, together with the delaying of multiplication of the amoebae, indicate that aureomycin is not directly lethal to the amoebae, but inhibits their reproductive faculties only.

SUMMARY.

The noteworthy features of the present investigations are:

- (1) There is evidence to show that aureomycin has a tendency to inhibit the reproductive activities of the trophozoites of *E. histolytica* without showing any marked lethal action on them, and
- (2) From the degenerative changes noticed in some amoebae treated with emetine, it is believed that while the weak ones among the protozoa may suffer directly from the effects of four hours' contact with 1 : 500 solution of this drug, the healthy ones escape its action and multiply freely.

ACKNOWLEDGEMENT.

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BOSE-EINSTEIN CONDENSATION AND THE PARTITION THEORY OF NUMBERS *

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1. INTRODUCTION.

The phenomenon of Bose-Einstein condensation, first studied by Einstein, came into lime light because of London's (1939) speculations which offered a mechanism for explaining the strange behaviour of liquid helium below the λ -point. Later Tisza (1938, 1947) developed a quantitative theory by uniting the properties of a liquid with the characteristic of B.E. degeneration. In spite of the great success of this scheme, the relevance of statistics to the properties of liquid helium has been repeatedly questioned on various grounds. In recent years, the reality of condensation even for an ideal gas has been thrown in doubt because of Schubert's (1946) demonstration of the failure of the 'saddle-point' method in the degenerate B.E. case. It has therefore become necessary to use alternative methods to study the true nature of this strange phenomenon.

The problem in the general case bristles with difficulties. But recently Temperley (1949) considered a simple thermodynamic assembly which is amenable to the methods of analytic theory of partitions and thus provides an important check on the results of the orthodox theory. In the present paper some new results are obtained for the same assembly. These throw more light on the problem and help to clear some controversial points.

2. TEMPERLEY'S TREATMENT OF THE MODEL WITH EQUIDISTANT ENERGY LEVELS.

Let n denote the energy of the assembly of N particles in terms of the separation between two adjacent levels. The orthodox theory readily gives

$$N = \sum_{r=0}^{\infty} \frac{1}{Ae^{\mu r} - 1}, \quad n = \sum_{r=0}^{\infty} \frac{r}{Ae^{\mu r} - 1}, \quad \dots \quad (1)$$

where μ is the inverse of temperature in energy units and A is the degeneracy parameter. An application of Poisson's formula to (1) gives

$$N - \frac{1}{A-1} + \frac{1}{2} \cdot \frac{1}{Ae^{\mu} - 1} = -\frac{1}{\mu} \log \left(1 - \frac{e^{-\mu}}{A} \right) + \frac{A^{-1}e^{\mu}}{1 - A^{-1}e^{\mu}} O(\mu), \quad \dots \quad (2a)$$

and

$$n + \frac{1}{2} \cdot \frac{1}{Ae^{\mu} - 1} = \frac{1}{\mu^2} \sum_{s=1}^{\infty} \frac{A^{-s}e^{-\mu s}}{s^2} - \frac{1}{\mu} \log \left(1 - \frac{e^{-\mu}}{A} \right) + R, \quad \dots \quad (2b)$$

where R becomes at most of order μ^{-1} as $A \rightarrow 1$.

* The present investigation was undertaken in 1950 and formed a part of the thesis submitted by the author in early 1951. The communication of the results, however, has been delayed due to certain unavoidable reasons.

Consider the case $\mu \rightarrow 0$ (i.e. $n \rightarrow \infty$). It is clear from equation (2a) that when $A = 1 + (\log N/N)$, the second and third term on the right are negligible as compared to N . Therefore one gets

$$N \sim \frac{1}{\mu} \log \frac{1}{\mu}, \quad \dots \quad (3a)$$

and

$$n \sim \frac{\pi^2}{6\mu^2}, \quad \dots \quad (3b)$$

If A takes a value slightly smaller than $1 + O(1)/N$ the right side of equation (2a) is practically unaffected but the term $1/(A-1)$ now contributes effectively to N . This situation is similar to that of condensation in a perfect gas. Using equations (3a) and (3b) it is clear that when the number of particles in the assembly exceeds $\{\sqrt{(6n)/2\pi}\} \log n$ the expression for particles in the excited states is not altered.* The only term to be affected is $1/(A-1)$ which determines the mean occupation number of the lowest state.

The above model can also be treated according to the methods of analytic theory of partition. Let $p_N(n)$ denote the number of partitions of n into N or less parts, then

$$\sum_n \sum_N p_N(n) z^N x^n = \frac{1}{(1-z)(1-zx)(1-zx^2) \dots}, \quad \dots \quad (4a)$$

which leads to

$$\sum_n p_N(n) x^n = \frac{1}{(1-x)(1-x^2) \dots (1-x^N)}. \quad \dots \quad (4b)$$

If \bar{N}_r denotes the mean occupation number of the r -th state then

$$\sum_n \sum_N \bar{N}_r p_N(n) x^n z^N = \frac{zx^r}{1-zx^r} \cdot \frac{1}{(1-z)(1-zx)(1-zx^2) \dots}, \quad \dots \quad (5)$$

which after a little algebra gives

$$\sum_n \bar{N}_r p_N(n) x^n = \frac{x^r(1-x^N) + x^{2r}(1-x^N)(1-x^{N-1}) + \dots}{(1-x)(1-x^2)(1-x^3) \dots (1-x^N)}. \quad \dots \quad (6)$$

Therefore

$$\begin{aligned} \sum_n \bar{N}_0 p_N(n) x^n &= \frac{(1-x^N) + (1-x^N)(1-x^{N-1}) + \dots}{(1-x)(1-x^2) \dots (1-x^N)} \\ &= \frac{N}{(1-x)(1-x^2) \dots (1-x^N)} - h_N, \quad \dots \quad (7) \end{aligned}$$

where

$$h_N = \frac{Nx^N}{(1-x)(1-x^2) \dots (1-x^N)} + \frac{(N-1)x^{N-1}}{(1-x)(1-x^2) \dots (1-x^{N-1})} + \dots + \frac{x}{(1-x)}. \quad (8)$$

* This is also Temperley's attitude regarding the onset of condensation according to the customary theory but the value given by him is double that of the one quoted here. In fact, it appears that his treatment here is not quite correct. As an illustration for $A = 1 + O(1)/N^{\frac{1}{2}}$ equation (7) of his paper gives $N \sim \frac{1}{\mu} \log \frac{1}{\mu}$ whereas on careful consideration we find $N \sim (\frac{1}{2}\mu) \log (1/\mu)$.

Combining (4b) and (7) we find

$$\sum_n (N - \bar{N}_0) p_N(n) x^n = h_N. \quad \dots \dots \dots (9)$$

Since $P_N(n)$ becomes independent of N for $N \geq n$, and equation (8) shows that the coefficient of x^n in (8) becomes independent of N for $N \geq n$, therefore $N - \bar{N}_0$, the mean occupation number of the excited states, becomes independent of N for $N = n$.

The distribution formula can be obtained by making use of the saddle-point method which can be formally shown to be valid for evaluating the ratio of coefficients of x^n in (4b) and (6). This gives

$$\bar{N}_r = e^{-\mu r} (1 - e^{-\mu N}) + e^{-2\mu r} (1 - e^{-\mu N}) (1 - e^{-\mu(N-1)}) + \dots, \quad \dots (10)$$

where $e^{-\mu}$ denotes the value of x at the saddle-point. If the customary theory is correct in the transition region it should be possible to put equation (10) in the form

$$\bar{N}_r = \frac{1}{\lambda_{N,r} e^{\mu r} - 1} \quad \dots \dots \dots (11)$$

where $\lambda_{N,r} = (1 + \delta_{N,r})$, $\delta_{N,r}$ being a small quantity which may depend on N but whose leading terms must be independent of r .

From equation (10) we obtain

$$\bar{N}_r(N) = e^{-\mu r} (1 - e^{-\mu N}) (1 + \bar{N}_r(N-1)) \quad \dots \dots \dots (12)$$

Substituting (12) in (11) we obtain

$$\delta_{N,r} = e^{-\mu N} (1 - e^{-\mu r}) + e^{-\mu r} \delta_{N-1,r} + O(e^{-2\mu N}), \quad \dots \dots (13)$$

whence it follows that

$$\left. \begin{aligned} \delta_{N,r} &\approx e^{-\mu N} (1 - e^{-\mu r}) / (1 - e^{-\mu(r-1)}), \quad r \geq 2 \\ \text{and} \\ \delta_{N,r} &\approx N e^{-\mu N} (1 - e^{-\mu}), \quad r = 1. \end{aligned} \right\} \quad \dots \dots (14)$$

This shows that $\delta_{N,r}$ is not independent of r .

To sum up Temperley's conclusions broadly are: (i) The condensation phenomenon is a real one, (ii) The onset of condensation is not located correctly by orthodox theory, (iii) The orthodox distribution formula is valid at very high and very low temperatures but fails completely in the transition region.

3. THE MEAN STATE AND MOST PROBABLE STATE.

It is usual in statistical mechanics to assume that the mean state of an assembly, obtained by averaging over all the accessible states, is identical with the most probable state. Here we shall have an opportunity of testing how far this assumption is justified. If \bar{N}_0 denotes the mean occupation number of the zero state the excited states can be occupied in $P_{N-\bar{N}_0}(n)$ ways, where $P_K(n)$ denotes the number of partitions of n into exactly K parts. The properties of the function $P_K(n)$ have been studied by Auluck, Chawla and Gupta (1942), who have given numerical and theoretical evidence to support the view that it possesses a unique maximum k_0 . When $N < k_0$ the largest number of arrangements are obtained by putting $\bar{N}_0 = 0$, while for $N > k_0$, we shall get the maximum number of arrangements when $\bar{N}_0 = N - k_0$. If it is assumed that the mean state is identical with

the most probable state, the mean occupation numbers of the excited states would become independent of N for $N \geq k_0$. Thus condensation should occur at $N = k_0$. It has been shown by Erdős's (1946) that

$$k_0 = \frac{\sqrt{(6n)}}{\pi} \log \frac{\sqrt{(6n)}}{\pi} + o(n^{\frac{1}{2}}). \quad \dots \dots \dots (15)$$

The algebraic treatment of Temperley, however, places the transition region at $N = n$. Since the two values are widely different therefore he concludes that the mean state and the most probable state are not identical for this assembly. But it appears necessary first to deduce an expression for the former too.

4. AN EXPRESSION FOR THE MEAN STATE $\bar{M}(N)$.

The mean state of the assembly is defined by

$$\bar{M}(N) = \frac{\sum_{k=1}^N k P_k(n)}{\sum_{k=1}^N P_k(n)} \dots \dots \dots (16)$$

We shall first consider the case $N = n$ for which the above equation can be written in the form

$$\bar{M}(n) = n - \frac{p_{n-1}(n) + p_{n-2}(n) + \dots}{p(n)} \dots \dots (17a)$$

From equation (7)

$$\bar{N}_0 p(n) = p_{n-1}(n) + p_{n-2}(n) + \dots \dots \dots (17b)$$

therefore

$$\bar{M}(n) = n - \bar{N}_0.$$

This shows that $\bar{M}(n)$ can be obtained from the number of particles in the excited states, where the total number of particles in the assembly is n (or greater than n). For this case the accessible states of the assembly become equal to $p(n)$ and the 'Zustandsumme' Z is given by

$$Z = \sum_n p(n) e^{-n\mu} = \prod_{r=1}^{\infty} (1 - e^{-\mu r})^{-1} \dots \dots (18)$$

Therefore, the mean occupation number

$$\bar{N}_r = - \frac{1}{\mu} \frac{\partial \log Z}{\partial \epsilon_r} = \frac{1}{e^{\mu r} - 1}, \quad r \geq 1. \quad \dots \dots (19)$$

Hence

$$N - \bar{N}_0 = \sum_{r=1}^{\infty} \frac{1}{e^{\mu r} - 1}.$$

To sum the series consider the function

$$f(y) = \frac{1}{e^{\mu y} - 1} - \frac{1}{\mu y} + \frac{1}{2}, \quad \mu > 0.$$

We can also write

$$f(y) = \frac{B_2}{2!} \mu y + \frac{B_4}{4!} (\mu y)^3 + \dots$$

where B_2, B_4, \dots are the Bernoulli numbers. Thus

$$f(0) = 0$$

and

$$f^{(p)}(0) = \frac{B_{p+1}}{(p+1)!} \mu^p,$$

where $f^{(p)}(y) \big|_{y=q}$ denotes the p -th differential of $f(y)$ at $y = q$. Using now the Euler-Maclaurin Formula we can write

$$\begin{aligned} \sum_{r=0}^n f(r) &= \frac{1}{e^\mu - 1} + \frac{1}{e^{2\mu} - 1} + \dots + \frac{1}{e^{n\mu} - 1} - \frac{1}{\mu} \left(1 + \frac{1}{2} + \dots + \frac{1}{n} \right) + \frac{n}{2} \\ &= \int_0^n f(y) dy + \frac{1}{2} (f(n) + f(0)) + \frac{B_2}{2!} f'(y) \Big|_0^n + \dots \\ &= \frac{1}{\mu} \left| \log \frac{(1 - e^{-\mu y})}{y} + \frac{y}{2} \right|_0^n + \frac{1}{2} (f(n) + f(0)) + \frac{B_2}{2!} f'(y) \Big|_0^n + \dots \end{aligned}$$

Since

$$\left(1 + \frac{1}{2} + \frac{1}{3} + \dots + \frac{1}{n} \right) - \log n \rightarrow \gamma,$$

where γ is Euler's constant and $f(n) \rightarrow \frac{1}{2}$, therefore we get

$$\bar{M}(n) = \sum_{r=1}^{\infty} \frac{1}{e^{\mu r} - 1} = \frac{1}{\mu} \left(\log \frac{1}{\mu} + \gamma \right) + \frac{1}{4} + O(\mu), \quad \dots \quad (20)$$

as for $\mu \rightarrow 0$, $f^{(p)}(n) \rightarrow 0$. The energy of the assembly is given by

$$\begin{aligned} n &= - \frac{\partial}{\partial \mu} \log Z \\ &= \sum_{r=1}^{\infty} \frac{r}{e^{\mu r} - 1} = \frac{\pi^2}{6\mu^2} - \frac{1}{2\mu} + \frac{1}{24} + O(\mu). \quad \dots \quad (21) \end{aligned}$$

Inverting this we have

$$\frac{1}{\mu} = \frac{\sqrt{(6n)}}{\pi} + \frac{3}{2\pi^2} + O(n^{-1}),$$

which on substitution in (20) gives

$$\bar{M}(n) = \frac{\sqrt{(6n)}}{\pi} \left\{ \log \frac{\sqrt{(6n)}}{\pi} + \gamma \right\} + \frac{3}{2\pi^2} \left\{ \log \frac{\sqrt{(6n)}}{\pi} + \gamma + 1 + \frac{\pi^2}{6} \right\} + O(n^{-1}). \quad \dots \quad (22)$$

In Table I the values of $\bar{M}(n)$ obtained from equation (16) by the help of partition tables are compared with those calculated from equation (22).

TABLE I.

n	$\bar{M}(n)$ from Equation (16)	$\bar{M}(n)$ from Equation (22)
10 ..	4.57	4.27
20 ..	7.38	7.05
30 ..	9.74	9.38
40 ..	11.82	11.45
50 ..	13.74	13.35
100 ..	21.73	21.32

Using relations (16) and (22) we get the important result

$$\lim_{n \rightarrow \infty} \frac{\bar{M}(n)}{k_0} = 1.$$

This shows that in the present case for a very large assembly we can certainly regard the mean state and the most probable states as identical.

5. VARIATION OF $\bar{M}(N)$ WITH N .

Now we shall study the variation of the important quantity $\bar{M}(N)$ with N . It has been shown earlier that $\bar{M}(N)$ becomes completely independent of N for $N > n$. Hence for such values of N a plot of $\bar{M}(N)$ against N will be a straight line parallel to the axis of N . No results have been given so far for the case $N < n$.

Equation (16) can be written in the form

$$\bar{M}(N) = N - \frac{p_{N-1}(n) + p_{N-2}(n) + \dots}{P_N(n)}$$

Substituting from equation (16) we easily get

$$\bar{M}(N) = \bar{M}(n) \frac{p(n)}{p_N(n)} - \left(n \frac{p(n)}{p_N(n)} - N \right) + \frac{p_{n-1}(n) + \dots + p_N(n)}{p_N(n)}. \quad (23)$$

The properties of $p_N(n)$ have been investigated by Erdős's and Lehner (1941) who have shown by the help of Hardy-Ramanujan formula for $p(n)$ and the sieve formula of Eratosthenes that

$$p_N(n) \sim p(n) e^{-\frac{\sqrt{(6n)}}{\pi}} e^{-N\pi/\sqrt{(6n)}}$$

Taking account of the error terms in their deduction we obtain

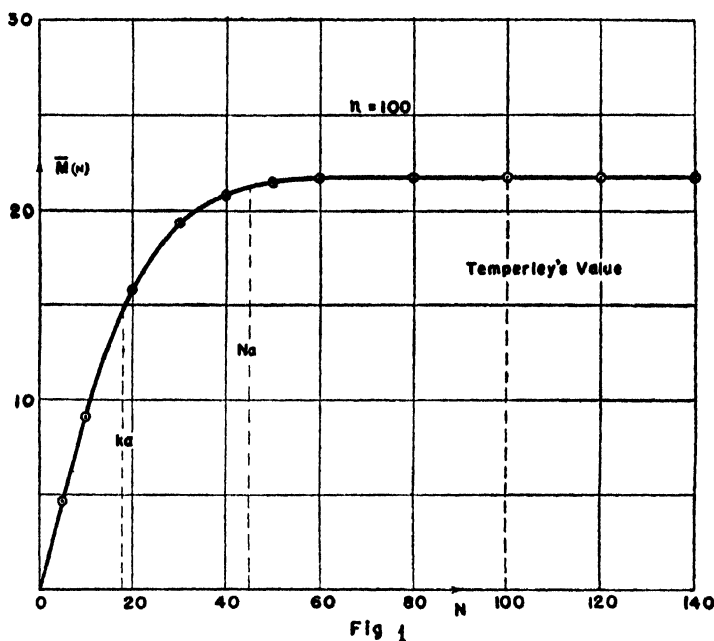
$$p_N(n) = p(n) e^{-\frac{\sqrt{(6n)}}{\pi}} e^{-N\pi/\sqrt{(6n)}} \left\{ 1 + O(e^{-N\pi/\sqrt{(6n)}} \log n) \right\}. \quad (24)$$

Substituting this value of $p_N(n)$ in (23) for the case

$$N = N_a = \left(1 + \frac{1}{S} \right) \{ \sqrt{(6n)/\pi} \} \{ \log (6n/\pi^2) \} \text{ we have}$$

$$\bar{M}(N) = \bar{M}(n) + O(n^{-1/5}), \quad \dots \quad (25a)$$

where S is large but finite. This shows that as the number of particles in the assembly is increased from N_a to n , the population of the excited states remains fixed. Thus, condensation according to Temperley's attitude must be ascribed to $N = N_a$ on physical grounds. It is also clear that a plot of $\bar{M}(N)$ would become parallel to the axis of N for $N > N_a$ in the limit of a large assembly. Even for such a small value of n as hundred this feature is brought out clearly in Fig. 1. (The



values of $\bar{M}(N)$ have been obtained from equation (16) by the help of partition tables.) The curve does not, however, represent the true trend of variation of $\bar{M}(N)$ between k_0 and N for large n . Actually, for $k_0 < N < N_a$ $\bar{M}(N)$ increases so slowly that for sufficiently large n we can treat $\bar{M}(N)$, to a first approximation, as a constant quantity.

Consider the case where $N = N_b$, where $N_b = (1 + 1/S) (\sqrt{(6n)/\pi}) \log \sqrt{(6n)/\pi}$ and S as before can take large but finite values. It is evident that N_b becomes equal to k_0 as $S \rightarrow \infty$. Equations (23) and (24) give for this case

$$\begin{aligned} \bar{M}(N) e^{-\{\pi/\sqrt{(6n)}\}^{1/S}} &= \bar{M}(n) - N_b \left\{ (\pi/\sqrt{(6n)})^{1/S} - \frac{1}{2!} (\pi/\sqrt{(6n)})^{2/S} + \dots \right\} \\ &\quad - \frac{\sqrt{(6n)}}{\pi} \left\{ (\pi/\sqrt{(6n)})^{1/S} + \frac{1}{2 \cdot 2!} (\pi/\sqrt{(6n)})^{2/S} + \dots \right\} \\ &\quad + O\left(\frac{\log n}{(\sqrt{n})^{1/S}}\right). \quad \dots \quad (25b) \end{aligned}$$

This shows that even for $S \rightarrow \infty$ (i.e. $N = k_0$),

$$\bar{M}(n) = \bar{M}(N) + O(n^{\frac{1}{2}}).$$

6. A THERMODYNAMIC APPROACH TO CONDENSATION PROBLEM.

So far following Temperley we have regarded the condensation to occur at a stage at which the mean occupation numbers of the excited states become independent of N . This point of view is rather abstract. It appears that a more realistic approach would be to regard the condensation to have set in at a stage at which a finite fraction of the total number of particles begin accumulating in the ground state. From the thermodynamic point of view this value would be of greater interest as it is here that the strange kinetic effects associated with condensation in momentum space would be first observed.

From equation (25b) we notice that for $N = N_0$

$$\bar{N}_0 = \frac{1}{S} \frac{\sqrt{(6n)}}{\pi} \log \frac{\sqrt{(6n)}}{\pi}$$

Therefore,

$$\text{Lt } \frac{\bar{N}_0}{N} = 1/S.$$

On the other hand, when $N = k_0$

$$\bar{N}_0 = O(n^{\frac{1}{2}})$$

which shows

$$\frac{\bar{N}_0}{N} \rightarrow 0.$$

Thus, it is clear that when N increases from k_0 to N_0 a finite fraction of the total number of particles collect in the state of lowest energy. Hence the condensation according to the present attitude occurs at $N = k_0$.

A similar situation is also described by the orthodox distribution formula

$$\bar{N}_r = \frac{1}{A e^{\mu r} - 1} \quad \dots \quad \dots \quad \dots \quad (26)$$

Consider first the value $A = 1 + \mu$. We have then

$$\bar{N}_0 = \frac{1}{\mu},$$

while (2a) gives

$$N \sim \frac{1}{\mu} \log \frac{1}{\mu} + O(1/\mu)$$

Hence

$$\frac{\bar{N}_0}{N} \sim 1 / \log \frac{1}{\mu},$$

which tends to zero. Let A now take a slightly smaller value $A = 1 + \frac{S\mu}{\log \mu}$ where S is large but finite. Then equation (26) gives

$$\bar{N}_0 = \frac{1}{S\mu} \log \frac{1}{\mu}$$

while from (2a) we have

$$N \sim \frac{1 + 1/S}{\mu} \log \frac{1}{\mu}.$$

Therefore now

$$\frac{\bar{N}_0}{N} \sim \frac{1}{S}$$

Thus, if the condensation is supposed to occur at a stage at which a finite fraction of the total number of particles accumulate in the lowest state then the value obtained from the orthodox theory and the rigorous methods of analytic theory of partitions is the same.

It can be easily shown from Temperley's own result that the distribution formula (26) gives the mean occupations correctly to a first approximation even in the transition region. Consider the case when $N = N_b$. From equation (14) we obtain

$$\delta_{N,r} \approx \frac{r}{r-1} \mu^{1+1/S}, \quad r \geq 2$$

and

$$\delta_{N,1} \approx -(\log \mu \mu^{1+1/S}).$$

On the other hand, from the orthodox theory for $N = N_b$ as we have already seen

$$A = 1 - \frac{S\mu}{\log \mu}$$

and therefore

$$\delta \approx S\mu/(\log 1/\mu).$$

It is thus clear that $\delta \ll \mu$ in all the cases. From (11) we notice that for $\delta \ll \mu r$ the leading term in N is $1/\mu r$ which is independent of the value of δ .

7. CONCLUSION.

It was shown by Temperley that for all models with non-degenerate ground state the mean occupation numbers of excited states become independent of N for $N > n$, where n the energy of the assembly is expressed in terms of separation between the ground state and the first excited state. This result is mathematically exact. It is, however, shown here for the model with equidistant energy levels that the dependence of $N - \bar{N}_0$ on N remains of no physical interest for $N > N_a$ where

$$N_a = C \cdot \frac{\sqrt{6n}}{\pi} \log \frac{6n}{\pi^2}, \quad C > 1.$$

Hence, if condensation is supposed to occur when the mean occupation number of excited states become independent of N , then it has to be ascribed to $N = N_a$.

On the other hand, if condensation is defined by the value of N at which a finite fraction of the total number of particles begin to collect in the lowest state, then this transition must be attributed to $N = k_0$, where

$$k_0 \sim \frac{\sqrt{(6n)}}{\pi} \log \frac{\sqrt{(6n)}}{\pi}.$$

The present investigation suggests the need of carrying out a similar study in connection with other models as well. It would be interesting to investigate whether the condensation values N_a and k_0 , according to the two attitudes, remain distinct or coincide in these cases. This problem will be taken up in a subsequent paper.

ABSTRACT.

In the present paper the thermodynamics of a Bose-Einstein assembly, with equidistant energy levels, is investigated by the rigorous methods of analytic theory of partitions in order to check the results obtained by the orthodox formula. Such an investigation has become necessary due to a demonstration by Schubert of the failure of the 'saddle-point method' in the degenerate Bose-Einstein case.

The results obtained here may be regarded as an extension of the work begun by Temperley (though the conclusions drawn are in many ways different) who has shown that the orthodox distribution formula is valid only at very high and very low temperatures but fails completely for the intermediate temperatures. He also doubted the validity of the assumption about the identity of the mean state and the most probable state for the present model. Temperley, however, did not give an expression for the mean state. Here we have obtained an exact expression for the mean state and shown that this agrees with the most probable state in the limit of a very large assembly. Further, it is proved that besides the condensation value given by Temperley there are two other values, depending on the definition used, at which condensation can be supposed to occur. It is also noticed that the orthodox distribution formula gives results which are correct to a first approximation even in the transition region.

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ORIGINAL OF $p^{-\lambda}_{q+1}F_q(-p^\alpha)$ AND ITS INTEGRAL REPRESENTATION¹

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1. BARNES'S INTEGRAL FOR ${}_{q+1}f_q(-z)$.

By Cauchy's theory of residues it may be shown that if

$$\phi(s) \equiv \Gamma(c+s) \prod_{n=1}^q \{ \Gamma(a_n+s)/\Gamma(b_n+s) \},$$

$$\text{then} \quad \frac{1}{2\pi i} \int_{-100}^{100} \phi(s) \Gamma(-s) z^s ds = \sum_{r=0}^{\infty} \phi(r) (-z)^r / r! \quad \dots \quad (1)$$

$$= {}_{q+1}f_q(a_1, \dots, a_q; c; b_1, \dots, b_q; -z) = f(z), \text{ say,} \quad \dots \quad (2)$$

in the case when $|z| < 1$, $|\arg z| \leq \pi - \epsilon$, ϵ being an arbitrary positive number. The path of integration is the imaginary axis modified, if necessary, by loops to make the poles of $\Gamma(c+s)$, $\Gamma(a_n+s)$, $n = 1, 2, \dots, q$, lie to the left of the path and those of $\Gamma(-s)$ to its right. This is always possible provided that none of the numbers c, a_1, a_2, \dots, a_q is a negative integer; we further suppose that no two of these numbers are equal or differ by an integer.

2. ANALYTICAL CONTINUATION OF ${}_{q+1}f_q$.

As shown² by Thomae (1870) and MacRobert (1938) the analytical continuation of the function ${}_{q+1}f_q(-z)$ for the range $|z| > 1$, $|\arg z| \leq \pi - \epsilon$ is

$$\sum_{j=0}^q \prod_{n=1}^q \frac{\Gamma(a_n^* - a_j)}{\Gamma(b_n - a_j)} \frac{\Gamma(a_j)}{z^{a_j}} {}_{q+1}F_q \left(\begin{matrix} a_j, 1+a_j-b_r; \\ 1+a_j-a_r^* \end{matrix}; -\frac{1}{z} \right) = F(z), \text{ say,} \quad \dots \quad (3)$$

where $a_0 = c$, the suffix r runs from 1 to q and the asterisk* over a_n (or a_r) indicates that when the subscript n (or r) is equal to j , a_n (or a_r) is to be replaced by c .

To show this we observe that the integral (1) represents an analytic function, regular in the z -plane supposed cut along the real axis from 0 to $-\infty$, and so provides the analytical continuation of $f(z)$ all over the plane. For in any closed domain of the cut plane, there holds an inequality $|\arg z| \leq \pi - \epsilon$, where ϵ is a positive constant. Since when u is finite and $|v|$ large (Copson, 1935)

$$|\Gamma(u+iv)| \sim \sqrt{(2\pi)} |v|^{u-1/2} e^{-\pi|v|}, \quad \dots \quad (4)$$

it follows that if $s = it$, where t is real and $|t|$ large, then

$$|\phi(s) \Gamma(-s) z^s| < K |t| \rho e^{-\epsilon|t|},$$

¹ Read at the Indian Science Congress, Jan. 1952.

² I am indebted to the referee for pointing out this reference.

where K and ρ are constants independent of t and z . This implies that the Barnes's integral (1) converges uniformly in the closed domain and so represents a regular analytic function. Replacing the path by a closed contour consisting of the given line and an infinite semicircle to the left of the y -axis, and taking the sum of the residues at the poles within the contour, we get the expression (3) for the integral.

Thus $f(z)$ and $F(z)$, as defined in (2) and (3) are both given by the integral (1), the first for the range $|z| < 1$, $|\arg z| < \pi$, and the latter for $|z| > 1$, $|\arg z| < \pi$ and provide analytic continuations one of the other all over the cut plane.

3. THE ORIGINAL OF ${}_{q+1}f_q(-p^\alpha)$.

Consider the integral

$$h(p) = p \int_0^\infty e^{-px} \frac{dx}{2\pi i} \int_{-i\infty}^{i\infty} \frac{\phi(-s)\Gamma(s)}{\Gamma(\lambda+1+\alpha s)} x^{\lambda+\alpha s} ds, \quad \dots \quad (5)$$

when $0 < \alpha < 2$ and $x > 0$. By virtue of (4) the inner integral in (5) is absolutely convergent. Also the x -integral is absolutely convergent if $R(\lambda) > -1$, and the double integral exists. Hence by de la Vallée Poussin's theorem (Bromwich, 1926) we may invert the order of integration and have

$$\begin{aligned} h(p) &= \frac{1}{2\pi i} \int_{-i\infty}^{i\infty} \phi(-s)\Gamma(s)p^{-(\lambda+\alpha s)} ds \\ &= p^{-\lambda} f(p^\alpha) \text{ if } |p| < 1 \text{ and } p^{-\lambda} F(p^\alpha) \text{ if } |p| > 1, \end{aligned}$$

by (2) and (3) respectively. Since (Copson, 1935) when $|s|$ is large and $|\arg s| < \pi$,

$$\Gamma(s+\gamma) \sim |s|^{s+\gamma-\frac{1}{2}} e^{-s} / \sqrt{(2\pi)}, \quad \dots \quad (6)$$

the s -integral in (5) vanishes when taken round a semicircle at infinity to the right of the imaginary axis if $\alpha > 0$. Hence it is equal to minus the sum of the residues of the integrand at its poles to the right of the imaginary axis, i.e. equal to

$$\sum_{j=0}^q \sum_{r=0}^\infty \prod_{n=1}^q \frac{\Gamma(a_n^* - a_j - r)}{\Gamma(b_n - a_j - r)} \frac{\Gamma(a_j + r) x^{\lambda+\alpha(a_j+r)} (-)^r}{\Gamma(1+\lambda+\alpha a_j + \alpha r) r!} = \psi(x), \text{ say,} \quad \dots \quad (7)$$

where the asterisk and a_0 have the same meanings as in (3). We thus have the operational relation

$$p^{-\lambda} {}_{q+1}f_q \left(\begin{matrix} a_1, a_2, \dots, a_q, c \\ b_1, b_2, \dots, b_q \end{matrix} ; -p^\alpha \right) \subset \psi(x), \quad \dots \quad (8)$$

valid when $R(\lambda + \alpha) > -1$, $R(\lambda + \alpha_n) > -1$, $n = 1, 2, \dots, q$, and $0 < \alpha < 2$. The image function is defined by its analytic continuation, as given in § 2, when $|p| > 1$.

4. SPECIAL CASES.

An interesting special case of the relation (8) is afforded by taking $q = 1$. Dropping the suffixes from the parameters we have

$$\begin{aligned} p^{-\lambda} {}_2f_1 \left(\begin{matrix} a, c \\ b \end{matrix} ; -p^\alpha \right) &\subset \sum_{r=0}^\infty \frac{(-)^r \Gamma(c-a-r) \Gamma(a+r) x^{\lambda+\alpha(a+r)}}{r! \Gamma(b-a-r) \Gamma(1+\lambda+\alpha a + \alpha r)} \\ &+ \text{a similar expression with } a \text{ and } c \text{ interchanged.} \quad (9) \end{aligned}$$

This relation is valid when $R(\lambda + a\alpha) > -1$, $R(\lambda + c\alpha) > -1$.

(i) The original on the right is expressible by a Whittaker function if $\alpha = 1 = -\lambda$. Putting further $a = l + m + \frac{1}{2}$, $c = l - m + \frac{1}{2}$ and $b = l - k + 1$ we are led to the known relation (Goldstein, 1932)

$$p_2 f_1 \left(\begin{matrix} l+m+\frac{1}{2}, l-m+\frac{1}{2}, \\ l-k+1, -p \end{matrix} \right) \subset x^{l-1} e^{-1/x} W_{k,m}(x), \quad R(l \pm m) > -\frac{1}{2}.$$

(ii) The two infinite series on the right of (9) are expressible as one in the case $c = a + \frac{1}{2}$, and we have the relation

$$p^{-\lambda} {}_2f_1 \left(\begin{matrix} a, a+\frac{1}{2}, \\ b, -p^\alpha \end{matrix} \right) \subset \sqrt{\pi} \sum_{r=0}^{\infty} \frac{\Gamma(a+\frac{1}{2}r) (-2)^r x^{\lambda+\alpha(a+\frac{1}{2}r)}}{\Gamma(b-a-\frac{1}{2}r)r! \Gamma(1+\lambda+a\alpha+\frac{1}{2}\alpha r)}, \quad R(\lambda + a\alpha) > -1.$$

5. INTEGRAL REPRESENTATION OF $\psi(x)$.

We now apply to the relation (8) the theorem (Gupta, 1948) : If $f(p) \subset h(x)$, then for $\mu > 0$, $R(\rho) > -1$,

$$p^{\mu-\rho} f(p^{-\mu}) \subset H(x) \equiv x^\rho \int_0^\infty h(s) J_\rho^\mu(sx^\mu) ds,$$

where

$$J_\rho^\mu(t) \equiv \sum_{r=0}^{\infty} \frac{(-t)^r}{r!} \Gamma(1+\rho+\mu r),$$

provided that

(i) as $s \rightarrow 0$, $h(s) = o(s^{-1+\epsilon})$,

(ii) as $s \rightarrow \infty$, $h(s) = o[s^{k(\rho+1)-1-\epsilon'} \exp(-s^{k+\epsilon'' \cos \pi k} \cos \pi k)]$, k being equal to $1/(\mu+1)$ and $\epsilon, \epsilon', \epsilon''$ being arbitrarily small positive numbers, and

(iii) $\int_0^\infty e^{-px} |H(x)| dx$ converges.

To this end let

$$f(p) \equiv p^{-\beta} {}_{q+1}f_q \left(\begin{matrix} a_1, a_2, \dots, a_q, c; \\ b_1, b_2, \dots, b_q, \end{matrix} -\frac{1}{p^\nu} \right).$$

Then by termwise interpretation we find that

$$f(p) \subset h(x) \equiv \sum_{r=0}^{\infty} \frac{(-)^r}{r!} \prod_{n=1}^q \left\{ \frac{\Gamma(a_n+r)}{\Gamma(b_n+r)} \right\} \frac{\Gamma(c+r)x^{\beta+\nu r}}{\Gamma(1+\beta+\nu r)}.$$

Also taking $\rho - \mu(1+\beta) = \lambda$ and $\mu\nu = \alpha$, we know by (8) that

$$p^{\mu-\rho} f(p^{-\mu}) \equiv p^{\mu-\rho+\mu\beta} {}_{q+1}f_q \left(\begin{matrix} a_1, a_2, \dots, a_q, c; \\ b_1, b_2, \dots, b_q; \end{matrix} -p^{\mu\nu} \right) \subset \Psi(x).$$

Consequently the theorem furnishes the integral

$$\int_0^\infty J_\rho^\mu(sx^\mu) \left[\sum_{r=0}^{\infty} \frac{(-)^r}{r!} \prod_{n=1}^q \left\{ \frac{\Gamma(a_n+r)}{\Gamma(b_n+r)} \right\} \frac{\Gamma(c+r)s^{\beta+\nu r}}{\Gamma(1+\beta+\nu r)} \right] ds = \frac{\Psi(x)}{x^\rho}, \quad \dots \quad (10)$$

valid when—

$$(i) R(\beta) > -1, 0 < \mu < 1, 0 < \nu < 2;$$

or (ii) $R(\beta) > -1, \mu = 1, R(\beta - \nu c - \frac{1}{2}\rho) + \frac{1}{4} < 0, R(\beta - \nu a_n + \frac{1}{4} - \frac{1}{2}\rho) < 0, n = 1, \dots, q, 0 < \nu < 2;$

or (iii) $R(\beta) > -1, \mu = 1, \nu = 2, R(\beta - 2c - \frac{1}{2}\rho) + \frac{1}{4} < 0, R(\beta - 2a_n - \frac{1}{2}\rho) < -\frac{1}{4}, n = 1, \dots, q, \text{ and } R\{c - \frac{1}{2}\rho + \Sigma(a_n - b_n)\} < \frac{3}{4}.$

These conditions are obtained by using the asymptotic behaviours given by Wright (1935) and noting that either side of (10) represents an analytic function.

6. PARTICULAR CASES OF (10).

The integrand reduces to the product of the generalized Bessel Function and a hypergeometric function if $\nu = 1$ or 2.

(a) If we further take $\mu = 1$, i.e. if $\nu = 1 = \mu$, then

$$\begin{aligned} & \int_0^\infty s^{\beta-\frac{1}{2}\rho} J_\rho\{2\sqrt{(sx)}\}_{q+1} f_{q+1}\left\{\begin{matrix} a_1, \dots, a_q, c; \\ b_1, \dots, b_q, 1+\beta; \end{matrix} -s\right\} ds \\ &= \sum_{j=0}^q \prod_{n=1}^q \frac{\Gamma(a_n^* - a_j)}{\Gamma(b_n - a_j)} \frac{\Gamma(a_j) x^{\frac{1}{2}\rho - \beta + a_j - 1}}{\Gamma(\rho + a_j - \beta)} {}_{q+1}F_{q+1}\left\{\begin{matrix} a_j, 1-b_j + a_j; \\ \rho - \beta + a_j, 1-a_j^* + a_j; \end{matrix} -x\right\}, \end{aligned}$$

$R(\beta) > -1, R(\frac{1}{2}\rho - \beta + c) > \frac{3}{4}, R(\frac{1}{2}\rho - \beta + a_n) > \frac{3}{4}$, where the same notation is used as in (3).

The hypergeometric function in the integrand is expressible by a Kummer's function when $q = 1, a_1 = b_1$ or $1 + \beta$, the former of which gives a known integral (Erdelyi, 1936) while the latter provides the value of the integral

$$\int_0^\infty s^{\beta-\frac{1}{2}\rho-\frac{1}{2}c} e^{-is} J_\rho\{2\sqrt{(sx)}\} M_{-\frac{1}{2}c+b, \frac{1}{2}c-\frac{1}{2}}(s) ds.$$

(b) In case $\mu = 1$ and $\nu = 2$, (10) gives the value of

$$\int_0^\infty s^{\beta-\frac{1}{2}\rho} J_\rho\{2\sqrt{(sx)}\}_{q+1} F_{q+2}\left\{\begin{matrix} a_1, \dots, a_q, c; \\ b_1, \dots, b_q, \frac{1}{2} + \frac{1}{2}\beta, 1 + \frac{1}{2}\beta; \end{matrix} -\frac{1}{4}s^2\right\} ds$$

as the sum of $q+1$ functions of the type ${}_{q+1}F_{q+2}(-\frac{1}{4}s^2)$. Two of the special cases of this when the ${}_{q+1}F_{q+2}(-\frac{1}{4}s^2)$ in the integrand is expressible in terms of Bessel Functions are:—

(i) $q = 1, a_1 = \frac{1}{2}(1+\beta), c = 1 + \frac{1}{2}\beta$. Putting γ for $b_1 - 1$ we get

$$\begin{aligned} & \int_0^\infty s^{\beta-\frac{1}{2}\rho-\gamma} J_\rho\{2\sqrt{(sx)}\} J_\gamma(s) ds = \text{the sum of two } {}_2F_3\text{'s} \\ &= \frac{x^{\frac{1}{2}\rho}}{2^\gamma - \beta} \sum_{r=0}^\infty \frac{\Gamma(\frac{1}{2}(r+\beta+1)) (-2x)^r}{r! \Gamma(\rho+1+r) \Gamma(\frac{1}{2}(2\gamma-\beta+1-r))}, R(\beta) > -1, R(\rho+2\gamma-2\beta) > -\frac{3}{2}. \end{aligned}$$

(ii) $q = 2, a_1 = \beta, a_2 = c = \frac{1}{2}b_1 = \gamma$ and $b_2 = 2\nu - \beta + \frac{1}{2}$.

On using the formula (Bailey, 1935)

$${}_2F_3 \left\{ \begin{matrix} \frac{1}{2}(\mu+\lambda-1), \frac{1}{2}(\mu+\lambda), \\ \mu, \lambda, \mu+\lambda-1, \end{matrix} -z^2 \right\} = \frac{\Gamma(\mu) \Gamma(\lambda)}{(\frac{1}{2}z)^{\lambda+\mu-2}} J_{\mu-1}(z) J_{\lambda-1}(z),$$

we get after a little simplification

$$\begin{aligned} & \frac{\sqrt{\pi}}{x^{1\rho}} \int_0^\infty s^{2\beta-2\gamma-1\rho} J_\rho \{2\sqrt{(sx)}\} J_{\beta-\frac{1}{2}}(\frac{1}{2}s) J_{2\gamma-\beta-\frac{1}{2}}(\frac{1}{2}s) ds \\ &= \sum_{r=0}^\infty \frac{\Gamma(\beta-\gamma-\frac{1}{2}r) \Gamma(\gamma+\frac{1}{2}r) (-4)^r (\frac{1}{2}x)^{2\gamma-2\beta+r}}{\Gamma(\gamma-\frac{1}{2}r) \Gamma(\gamma-\beta-\frac{1}{2}r+\frac{1}{2}) \Gamma(\rho+1+2\gamma-2\beta+r)r!} \\ &+ \frac{\Gamma(2\gamma-2\beta) \Gamma(\beta) 2^{4\beta-4\gamma+1}}{\Gamma(2\gamma-\beta) \Gamma(2\gamma-2\beta+\frac{1}{2}) \Gamma(\rho+1)} {}_3F_4 \left\{ \begin{matrix} \beta, \beta-2\gamma+1, 2\beta-2\gamma+\frac{1}{2}; \\ \beta-\gamma+1, \beta-\gamma+\frac{1}{2}, \frac{1}{2}\rho+\frac{1}{2}, \frac{1}{2}\rho+1 \end{matrix} -\frac{1}{4}x^2 \right\}, \\ &R(\beta) > 0, R(\rho) > -\frac{3}{2}, R(2\gamma-2\beta+\frac{1}{2}\rho) > -\frac{3}{4}. \end{aligned}$$

SUMMARY.

Goldstein (1932) gave the original of the function $p {}_2F_1(-p)$. Here we investigate the original of the more general function $p^{-\lambda} {}_{q+1}F_q(-p^\alpha)$, and obtain an integral representation of it. To this end the hypergeometric function ${}_{q+1}F_q(-z)$ is represented by a contour integral of the Barnes's type, which is then employed to obtain the analytical continuation of the hypergeometric function outside the latter's circle of convergence. Using this integral we obtain by repeated integration and inversion of the order of integration the desired original $\Psi(x)$.

In the second part of the paper the theorem for deriving the original of $p^\mu {}_1F_1(p^{-\mu})$ from that of $f(p)$ is applied to the above operational relation to obtain an integral representation of $\Psi(x)$.

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ECOLOGICAL STUDIES OF TERMITES

PART I. POPULATION OF THE MOUND-BUILDING TERMITE, *ODONTOTERMES OBESUS* (RAMBUR). (ISOPTERA: FAMILY TERMITIDAE)

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(With 10 Tables.)

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I. INTRODUCTION.

Little work has been done on the population-structure of termite colonies as regards numbers. Holdaway, Gay and Greeves (1938) and Gay and Greeves (1940) made population studies of the Australian species *Eutermes exitiosus* Hill and *Coptotermes lacteus* (Frogg.) respectively. In India, Mukerji and Mitra (1949) made some observations on the proportions of soldiers, workers and nymphs (immature forms) in fungus-combs from the nest of *Odontotermes redemanni* (Wasmann). But information on the total population and the relative proportions of the different castes of any Indian species has hitherto been lacking. In the present paper an account is given of studies carried out on the qualitative and quantitative aspects of the termite population of the entire mound-colonies of *Odontotermes obesus* (Rambur). This is a common mound-building and fungus-cultivating termite found in North India.

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II. MATERIAL AND METHODS.

Mounds of varying sizes were chosen for population estimations (Table 1). These were located in a partially open habitat of chir pine (*Pinus longifolia*) plantation in the Demonstration Area of the Forest Research Institute, Dehra Dun.

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TABLE 1.

Height, diameter, etc. of mounds of Odontotermes obesus (Rambur), dug out in New Forest, Dehra Dun.

Mound No.	Date	Height of mound (in inches)	Diameter (in various directions) at base or ground level (in inches)	Girth of mound at base (in inches)
1	16 May, 1950	10.0	18	36
2	8 June, 1950	13.0	16; 13	48
3	13 October, 1950	15.5	22; 23; 25	80
4	22 December, 1949	43.3	....	163.8
5*	11 January, 1951	16.0	16; 20	..
6*	11 January, 1951	9.0	16; 18	..
7	4 June, 1951	14.0	18.5; 19; 22	58
8	11 June, 1951	18.0	21; 23; 23	78
9	26 June, 1951	24.0	19.5; 21.5; 23.5	66
10†	28 June, 1951	33.0	39; 40; 43	105

* These mounds were treated with the insecticide D.D.T. on the 8th January, 1951, and were dug out on the 11th. The queen could not be traced but the colony was found to be living.

† Emergence of alates had taken place on 27th June.

Mound Nos. 1-10 were dug out in the early mornings, taking all possible care that the entire population was collected, including those of the royal chambers. The broken portions of the mounds were brought to the laboratory. The individual termites were picked out and preserved in rectified spirit. The lot was then thoroughly cleaned of the sand, wood and other particles adhering to them.

For the estimation of the populations, random sampling was adopted instead of the 'whole count' method. The entire termite material from a mound was poured in a glass trough with a liberal quantity of rectified spirit and well stirred. For mound Nos. 1-4 random samples, each of a definite volume, were taken; this was ensured by using a single glass tube for determining the sample. For the remaining mounds the volume of the random sample varied from mound to mound. In the former case the uniform volume was ensured by tapping the sampling tube with the hand until the termites settled down in a compact mass. In the latter case the sampling tube was not tapped by hand but was directly emptied into a graduated tube, centrifuged for a length of time, until no more settling occurred, and the volume noted. In mound Nos. 8-10, owing to the quick development of fungus *Xylaria* overnight, the counting of the total number was abandoned, and only data of the percentage of different castes was obtained from the few samples taken.

Two methods were employed for further determination of actual numbers, viz., (i) the volume method; and (ii) the dry-weight method.

(i) *The volume method.*—For estimation of populations, three or more samples of known volume from the material from each mound were taken and counted according to castes, e.g., soldiers, workers and nymphs (immature forms). From these data the entire mound-populations of the colonies of mound Nos. 1-3 and 5-7 were calculated (Table 2).

(ii) *The dry-weight method.*—To test the comparative accuracy of this method, the samples mentioned above under the volume method were dried in a hot air oven at 102°-103°C. to a constant weight. The remaining material from each mound was dried similarly. Knowing the populations and dry weights of the samples, that of the entire mound was calculated (Table 3).

TABLE 2.

Population counts of the entire mound-colony of Odontotermes obesus (Rambur), by the volume method. (Cf. Table 3.)

Mound No.	Date	Population count			Total
		Workers	Soldiers	Nymphs	
1	16 May, 1950 ..	7,491	1,406	7,188	16,085
2	8 June, 1950 ..	13,555	2,972	19,600	36,127
3	13 October, 1950 ..	45,563	7,906	37,492	90,961
5	11 January, 1951 ..	20,053	1,996	7,966	30,016
6	11 January, 1951 ..	3,882	325	341	4,548
7	4 June, 1951 ..	18,166	2,224	12,900	33,290

TABLE 3.

Population counts of the entire mound-colony of Odontotermes obesus (Rambur), by the dry-weight method. (Cf. Table 2.)

Mound No.	Date	Population count			Total
		Workers	Soldiers	Nymphs	
1	16 May, 1950 ..	7,244	1,432	6,301	15,577
2	8 June, 1950 ..	13,881	3,043	20,074	36,998
3	13 October, 1950 ..	56,357	9,360	45,514	1,11,181
4	22 December, 1949 ..	1,83,345	14,876	78,740	2,76,961
5	11 January, 1951 ..	20,297	1,820	8,063	30,180
6	11 January, 1951 ..	4,038	338	354	4,730
7	4 June, 1951 ..	21,214	2,597	15,065	38,876

III. OBSERVATIONS ON POPULATIONS OF MOUNDS.

(a) *Population composition of mounds as a whole.*

Table 1 gives the data for the mounds dug during the three periods of termite activity, viz., the pre-swarmling period (May and June), post-swarmling period (October) and the 'mound-building' period (December and January).

Mound Nos. 1-4 and 7 were healthy because the royal pairs in them were in perfect health. Mound Nos. 5 and 6 were treated with the insecticide D.D.T. on the 8th of January 1951 and dug out 3 days later (11th January). Though the colony was alive, we may regard the population strengths of these colonies as below normal. Mound Nos. 8-10 were also healthy, but owing to quick development of fungus *Xylaria* within a few hours of the removal of the mound-material to the laboratory, the entire termite population could not be counted, most of the termites having been badly mauled; a fairly representative sample of the same was, however, taken, and this, it is believed, gives a fairly accurate comparative idea of the proportion of the different castes in those months.

Tables 2 and 3 give the population counts of entire mound-colonies by the volume and dry-weight methods. As the recovery of the entire population of a mound in its absolute completeness is hardly possible owing to a portion of the population being away on foraging duty, the figures arrived at should be regarded only as a conservative estimate of the entire mound (including the nest) population.

The error was sought to be partially minimised by examining the mounds in the early mornings when the entire termite population is likely to be in the mound.

A comparison of the population figures obtained by the volume and dry-weight methods from the same mound (Table 4) shows a discrepancy (taking the figure

TABLE 4.

*Comparison of population counts in *Odontotermes obesus* (Rambur), of the entire colonies of mound Nos. 1-3 and 5-7 by the volume and dry-weight methods.*

Mound No.	Girth of mound (in inches)	Population		Percentage difference (taking count by volume method as 100)
		Volume method	Dry-weight method	
1	36	16,085	15,577	- 3.3%
2	48	36,127	36,998	2.4%
3	80	90,961	1,11,181	+ 22.4%
5	..	30,014	30,180	+ 0.55%
6	..	4,548	4,730	+ 4.0%
7	58	33,290	38,876	+ 16.7%

obtained by the volume method as 100) of the order of -3.3% to +4.0% in the case of mounds Nos. 1, 2, 5 and 6, of +22.2% in mound No. 3 and +16.7% in mound No. 7. The high degree of difference in the figures obtained by the two methods in mound Nos. 3 and 7 may possibly be due to two reasons, *viz.*, imperfect drying and imperfect cleaning of the material, most probably the latter. Considering the relatively low weight of dry termites as compared to extraneous matter, *e.g.*, soil particles, pieces of wood, etc., even a small piece of sand grain will cause a larger degree of error in dry-weight method than in the volume method. It is, therefore, felt that the volume method is the more reliable of the two.

The proportions of the various castes in the colony is of considerable interest. Table 5 shows the percentage and proportion of various castes in the entire mound-population, while Table 6 gives the percentage of workers and soldiers in relation

TABLE 5.

*Proportion of the different castes in colonies of *Odontotermes obesus* (Rambur) in mound Nos. 1-10.*

Mound No.	Date	Percentage			Proportion (taking soldier as unity)		
		Workers	Soldiers	Nymphs	Workers	Soldiers	Nymphs
1	16 May, 1950	46.6	8.7	44.7	5.3	1	5.4
2	8 June, 1950	37.5	8.2	54.3	4.6	1	6.5
3	13 October, 1951	49.8	8.8	41.4	5.8	1	4.7
4	22 December, 1949	66.2	5.4	28.4	12.1	1	5.2
5	11 January, 1951	66.8	6.7	26.5	11.2	1	3.9
6	11 January, 1951	85.4	7.1	7.5	12.0	1	1.0
7	4 June, 1951	54.5	6.7	38.8	8.1	1	5.8
8	11 June, 1951	51.0	7.9	41.1	6.5	1	5.2
9	26 June, 1951	54.6	6.2	39.2	8.0	1	6.3
10*	28 June, 1951	53.2	4.0	42.8	13.0	1	10.5

* Swarming of alates from the mound took place the previous day (27 June, 1951).

to each other. It appears that the relative number of soldiers in reference to workers is greater in mound Nos. 1, 2, 7, 8 and 9 than in mound Nos. 4, 5 and 6. This difference is probably due to the fact that the mounds of the first group were dug in the pre-swarming period (May and June) when more soldiers (11-18%, Table 6) are needed to guard the exit holes for the alates at the time of swarming. In the post-swarming period (October), the proportion of soldiers is still high (14%). This figure gradually drops during the mound-building months (December and January) to 7-8%, which appears to be the minimum in a healthy colony. Correspondingly, the relative number of workers increases from about 85-86% in other months to about 91-92% in December and January, i.e. from 1 : 8 to 1 : 12 for the probable reason that they are required for mound-building.

The percentage of nymphs in the colony appears to be the lowest (28.4%, Table 5) in December and January as against 38-54% in May and June. This might be due to a temporary retardation in the rate of egg-laying by the queen prior to renewed vigorous activity for the production of the reproductives and other forms, and for keeping the strength of the colony normal after the swarming of the alates for colonising flights. However, it is interesting to note that the proportion of the nymphs to soldiers remains fairly uniform throughout the year (1 : 4.7 to 1 : 6.5, Table 5).

TABLE 6.

Proportion of workers to soldiers in the mound-colonies of Odontotermes obesus (Rambur) in mound Nos. 1-10.

Mound No.	Date	Percentage	
		Workers	Soldiers
1	16 May, 1950 ..	83.5	16.5
2	8 June, 1950 ..	82.0	18.0
3	13 October, 1950 ..	85.2	14.8
4	22 December, 1949 ..	92.4	7.6
5	11 January, 1951 ..	91.4	8.2
6	11 January, 1951 ..	92.3	7.7
7	4 June, 1951 ..	89.1	10.9
8	11 June, 1951 ..	86.5	13.4
9	26 June, 1951 ..	89.0	11.0
10*	28 June, 1951 ..	92.9	7.1

* Swarming of alates from the mound took place the previous day (27 June, 1951).

From mound No. 10 swarming of alates took place on the day previous to the day of examination and the various castes show the following percentage: workers 53.2, soldiers 4.0, nymphs 42.8. No explanation can be suggested for such a low percentage of soldiers.

The population of a mound no doubt depends upon its size. However, the data at hand are too scanty for suggesting any actual correlation between the two characters.

(b) *Population composition of fungus-combs (Tables 7-10).*

For determining the population composition of fungus-combs, various samples from mound Nos. 11-20 (situated in the same locality as the previous mounds) at different height-levels in the mound, viz., at, above or below ground-level, were taken. The dimensions of the fungus-combs varied, depending upon the size and the contour of the fungus-comb chambers in the walls of the mound. The termites were separated and counted by the 'whole count' method (Tables 7-9).

TABLE 7.

Population composition of fungus-combs in mound Nos. 11-20 of Odontotermes obesius (Rambur), found above ground-level.

Mound No.	Date (1952)	Size of fungus-comb (in cms.)	Height above ground-level (in cms.)	Population count			Percentage		
				Soldiers	Workers	Nymphs	Soldiers	Workers	Nymphs
11	4 June	4 × 4	44.0	1	18	281	0.3	6.0	93.7
"	"	8 × 5	28.0	5	122	822	0.5	12.9	86.6
"	"	12 × 5	8.0	34	72	136	14.1	29.8	56.2
12	5 June	6 × 4.5	15.5	4	40	28	6.1	60.7	45.2
13	7 June	7.5 × 4	24.0	0	11	25	0.0	30.6	69.4
17	13 June	10 × 7	15.0	11	55	447	2.2	10.7	87.1
18	16 June	7 × 5	55.0	3	74	28	2.8	70.5	26.7
19	17 June	6.5 × 4	10.0	2	52	49	1.9	50.5	47.6
Total				60	444	1,816	2.6	19.1	78.3

TABLE 8.

Population composition of fungus-combs in mound Nos. 11-19 of Odontotermes obesius (Rambur), found at the ground-level.

Mound No.	Date (1952)	Size of fungus-comb (in cms.)	Population count			Percentage		
			Soldiers	Workers	Nymphs	Soldiers	Workers	Nymphs
11	4 June	7 × 6	55	38	183	19.9	13.8	66.3
12	5 June	8 × 8	34	156	113	11.2	51.5	37.3
13	7 June	9 × 8	11	41	99	7.3	27.1	65.6
17	13 June	8 × 7	42	290	468	5.3	36.2	58.5
18	16 June	9 × 6	6	141	65	2.8	66.5	30.7
19	17 June	7 × 7	4	85	102	2.1	44.5	53.4
Total			152	751	1,030	7.9	38.8	53.3

It will be seen (Tables 7-10) that the proportion of the various castes vary greatly from mound to mound and within the mound, irrespective of height levels. This is to be expected, as the worker and soldier population is migratory and will leave the combs as soon as it is disturbed greatly. The larger proportion of nymphs (ca. 56-83%, average 79.4%) is, however, noticeable and suggests that the bulk of the nymphal populations in the mound resides in these fungus-combs. Nearly the same percentages were arrived at by Mukerji and Mitra (1949) in *Odontotermes redemanni* Wasmann, but it was not stated whether the samples taken were from one mound or many.

TABLE 9.

Population composition of fungus-combs found below ground-level in mound Nos. 11-20 of Odontotermes obesus (Rambur).

Mound No.	Date (1952)	Size of fungus-comb (in cms.)	Depth below ground-level (in cms.)	Population count			Percentage		
				Soldiers	Workers	Nymphs	Soldiers	Workers	Nymphs
11	4 June	6.5 × 5.0	22.0	26	38	693	3.4	5.0	91.6
12	5 June	2.0 × 2.0	49.0	6	22	384	0.6	2.2	97.2
13	7 June	6.0 × 5.0	30.0	5	6	442	1.1	1.3	97.6
14	9 June	7.0 × 5.0	11.0	17	326	1,940	0.7	14.3	85.0
"	"	11.0 × 7.0	20.0	100	753	3,334	2.4	18.0	79.6
15	9 June	6.0 × 4.0	30.0	4	60	594	0.6	9.1	90.3
"	"	5.0 × 5.0	45.0	4	162	301	0.9	34.7	64.4
16	11 June	9.0 × 6.0	30.0	33	211	917	2.8	18.2	79.0
"	"	9.0 × 7.0	35.0	58	269	1,908	2.6	12.0	85.4
17	13 June	12.0 × 7.0	24.0	44	84	738	5.1	9.7	85.2
18	16 June	11.0 × 4.0	30.0	14	25	241	5.0	8.9	86.1
19	17 June	9.0 × 6.5	41.0	10	125	552	1.5	18.2	80.3
20	20 June	6.5 × 5.5	10.0	6	72	241	1.8	22.6	75.6
"	"	11.5 × 6.0	12.0	29	327	684	2.8	31.4	75.8
Total				356	2,480	13,569	2.2	15.1	82.7

TABLE 10.

Relative population composition of fungus-combs of mound Nos. 11-20 of Odontotermes obesus (Rambur)

Mound No.	Date (1952)	Population count			Percentage		
		Soldier	Worker	Nymphs	Soldier	Worker	Nymphs
11	4 June ..	121	288	2,115	4.8	11.4	83.8
12	5 June ..	44	218	1,125	3.2	15.7	81.1
13	7 June ..	16	58	566	2.5	9.1	88.4
14	9 June ..	117	1,079	5,274	1.8	16.7	81.5
15	9 June ..	8	222	895	0.7	19.7	79.6
16	11 June ..	91	480	2,825	2.7	14.1	83.2
17	13 June ..	97	429	1,653	4.5	19.7	75.8
18	16 June ..	23	240	334	3.9	40.2	55.9
19	17 June ..	16	262	703	1.6	26.7	71.7
20	20 June ..	35	399	925	2.6	29.4	68.0
Total ..		568	3,675	16,415	2.8	17.8	79.4
Proportion ..		1	6.5	28.9	..	..	..

IV. SUMMARY.

1. Ten mounds of varying sizes of *Odontotermes obesus* (Rambur) were dug in various seasons in Dehra Dun for the estimation of their entire population.

2. The mound-population was counted by two methods, viz., the 'volume' and the 'dry-weight' methods; the former is believed to be the more reliable.

3. In the mound as a whole, in other than mound-building months, on an average, workers constitute 49%, soldiers 7.7% and nymphs 43.3% of the colony. In the mound-building months the composition is about 66.5% workers, 5.5% soldiers and 28.0% nymphs.

4. The population-composition of the fungus-combs was also studied; the proportion of nymphs is much higher here than elsewhere in the mound.

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ECOLOGICAL STUDIES OF TERMITES

PART II. OCCURRENCE OF DESERTED ROYAL CHAMBERS, THE DIRECTIONAL POSITION OF THE QUEEN, AND THE SIZE OF THE QUEEN WITH RESPECT TO MOUND-SIZE IN THE MOUND-BUILDING TERMITE, *Odontotermes obesus* (RAMBUR). (ISOPTERA: FAMILY TERMITIDAE)

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(With 3 Text-figures and 9 Tables.)

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I. INTRODUCTION.

Deoras (1949) mentioned that the queen of the mound-building termite invariably occupies the north-east sector of the mound and that it lies more or less parallel to the magnetic meridian, *i.e.*, the north-south direction. He, however, did not mention the species. The only common mound-building species in India belong to the genus *Odontotermes*; his remarks presumably apply to *Odontotermes redemanni* which occurs in South India.

In the present paper the statements of Deoras are tested with regard to *Odontotermes obesus* (Rambur) commonly occurring in Dehra Dun. In the course of work, interesting observations were also made regarding what, I believe, to be a phenomenon of the 'desertation' of the royal chambers by the royal pair, and the relation of mound-size to the size of the queen.

Acknowledgement—My grateful thanks are due to Major Dr. M. L. Roonwal for laboratory facilities in the Forest Research Institute, as well as for his guidance and supervision during this investigation.

II. MATERIAL AND METHODS.

Mounds of different sizes (Table 1) of *Odontotermes obesus* (Rambur), situated in a partially open habitat of *chir pine* (*Pinus longifolia*) plantation in the Demonstration Area of the Forest Research Institute, New Forest Estate near Dehra Dun, were examined. A tunnel about 60 cm. wide and 90 to 120 cm. deep, depending upon the size of the mound, was dug around each mound. Piece by piece the mound-material was then removed. When the ground-level was reached, a strong magnetic compass was placed at the centre of the mound, and four sectors, *viz.*, NE, NW, SE, and SW were marked. On further slicing the mound, the royal

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chamber was reached. In some cases *deserted* royal chambers were also met with in the central dome-shaped chamber of the mound (Table 2). After removing the ceiling of the deserted as well as inhabited royal chambers, and placing the magnetic compass *in situ*, the axial directions of the chambers and the queens were noted (Tables 4, 6 and 8).

TABLE 1.

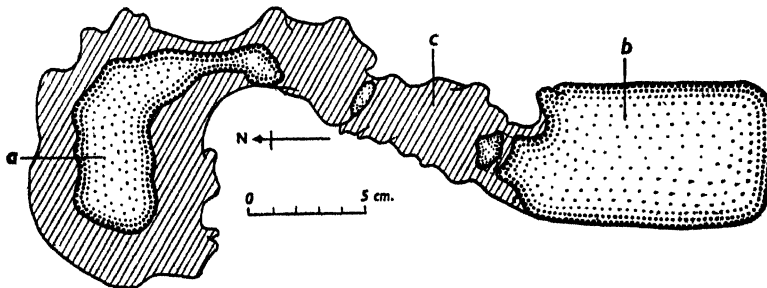
Height, diameter, girth, etc., of mounds of Odontotermes obesus (Rambur) in Dehra Dun.

Mound No.	Date (1952)	Height (in cms.)	Diameter at base (in cms.) Two readings at right angles	Girth (in cms.)
11	4 June	116.8	143 ; 129	396.2
12	5 June	63.0	76 ; 70	246.4
13	7 June	84.0	90 ; 98	274.3
14	9 June	42.0	56 ; 66	167.7
15	11 June	23.0	55 ; 53	172.7
16	11 June	26.2	55 ; 59	175.3
17	13 June	74.0	97 ; 100	302.3
18	16 June	114.5	109 ; 114	365.7
19	17 June	66.0	74 ; 84	256.5
20	20 June	13.5	25 ; 25	71.1
21	20 June	9.0	16 ; 12	45.7

III. OBSERVATIONS.

(a) Occurrence of deserted royal chambers.

Observations on a series of mounds of varying girths (and, thus, presumably of varying ages) showed that two types of royal chambers often occurred in a mound—one which was inhabited by the royal pair and another one (always connected with the former) which was uninhabited or deserted. In 11 mounds (Table 2) it was noticed that in mounds of lower girths (*ca.* 45–71 cm.) the inhabited royal chamber is found in the peripheral wall of the mound (Table 2); in mounds of intermediate girths (167–172 cm.) in the central dome; and in mounds of still higher girths (175–365 cm.) in the peripheral wall. It is worthy of note that all the mounds of the third or high girth-class category show two features: (1) There is invariably a 'deserted' royal chamber in addition to the inhabited one; and (2) the inhabited royal chamber lies peripherally in reference to the diameter of the mound. The deserted royal chamber is connected with the inhabited portion by means of a wide earth gallery (about 2 cm. in inner diameter, Text-fig. 1).



TEXT-FIG. 1. *Odontotermes obesus* (Rambur). A 'deserted' royal chamber, the 'connecting gallery and the 'inhabited' royal chamber.

a., deserted chamber; b., inhabited chamber; c., connecting gallery.

One is led to think that the royal chamber is first made in the peripheral wall of the mound. With the growth in mound-girth this chamber comes to lie into the growing central dome-shaped cavity of the mound and is now surrounded by the fungus-combs. Later, this chamber is 'extended' by the addition of a new chamber. The queen is probably transferred later to the newly made second royal chamber in the peripheral wall. The reasons for the formation of additional royal chamber are problematic. On comparing the inner dimensions of the 'inhabited' and 'deserted' royal chambers (Table 3), it will be noted that there is no significant difference, except in mound No. 18.

TABLE 2.

Occurrence of 'deserted' and 'inhabited' royal chambers in mounds of Odontotermes obesus (Rambur) in Dehra Dun.

+, presence; and —, absence of royal chambers of the particular kind indicated in column.

Mound No.	Girth (in cms.)	Royal chambers		
		Deserted	Inhabited	
			In central position	In wall
21	45.7	—	—	+
20	71.1	—	—	+
14	167.7	—	+	—
15	172.7	—	+	—
16	175.3	+	—	+
12	246.4	+	—	+
19	256.5	+	—	+
13	274.3	+	—	—
17	302.3	+	—	+
18	365.7	+	—	+
11	396.2	?	—	+

TABLE 3.

Length of the queen and the inner dimensions of the 'deserted' and 'inhabited' royal chambers in mounds of Odontotermes obesus (Rambur) in Dehra Dun.

Mound No.	Girth (in cms.)	Length of queen (in cms.)	Inner dimensions of royal chambers (in cms.)	
			Deserted	Inhabited
21	45.7	2.6	....	5.0 × 4.0
20	71.1	3.5	....	6.0 × 4.0
14	167.7	5.4	....	7.5 × 5.0
15	172.7	4.4	....	Not noted
16	175.3	5.2	Not noted	7.0 × 4.0
12	246.4	5.9	9.0 × 5.0	10.0 × 6.0
13	274.3	5.9	10.5 × 6.0	10.0 × 6.0
17	302.3	6.4	10.0 × 4.0	10.5 × 6.0
18	365.7	7.0	6.0 × 3.0	12.0 × 7.0
11	396.2	6.9	Not noted	10.0 × 6.0

TABLE 4.

Position of the royal chambers with respect to the ground-level and the centre of mound in Odontotermes obesus (Rambur) in Dehra Dun.

Mound No.	Position of royal chambers			
	'Deserted' royal chamber		'Inhabited' royal chamber	
	Directional sector	Depth below ground level (in cms.)	Directional sector	Depth below ground-level (in cms.)
11	Not noted	Not noted	NW	9.0
12	S	27.0	SE	32.0
13	N	32.0	NW	36.0
14	....	..	NW	50.0
15	....	..	NE	40.0
16	NE	35.0	NE	40.0
17	S	45.0	SW	37.0
18	W	11.0	W	0.0
19	Central	41.0	SE	34.0
20	....	..	NE	22.0
21	....	..	SW	13.5

TABLE 5.

Proportion of sectors in which royal chambers were found in mounds of Odontotermes obesus (Rambur) in Dehra Dun.

Sector	Percentage	
	Deserted	Inhabited
N	17	0
S	33	0
E	0	0
W	17	9
NE	17	27
SE	0	18
SW	0	18
NW	0	27
Central	17	0

TABLE 6.

Axial direction of the royal chambers with respect to magnetic meridian in mounds of Odontotermes obesus (Rambur) in Dehra Dun.

Mound No.	Axial direction of royal chambers	
	Deserted	Inhabited
11	Not noted	NS
12	EW	NS
13	NS	NS
14	..	NS
15	..	EW
16	NW	NW
17	NW	NW
18	NS	NS
19	NE	NS
20	..	NS
21	..	EW

TABLE 7.

Proportion of axial direction of royal chambers with respect to magnetic meridian in mounds of Odontotermes obesus (Rambur) in Dehra Dun.

Axial direction of royal chamber	Percentage	
	Deserted	Inhabited
NS	33	64
EW	17	18
NW (and SE)	33	18
NE (and SW)	18	0

TABLE 8.

Axial direction of the queen with respect to magnetic meridian in mounds of Odontotermes obesus (Rambur) in Dehra Dun.

Mound No.	Axial direction		Head facing
12	SE (changed NS) ..	..	SE
13	SE, 30° to NS axis	..	NW
14	NE, 30° to NS axis	..	NE
16	SE, 60° to NS axis	..	NW
17	SE, 30° to NS axis	..	SE
18	NE, 39° to NS axis	..	SW
19	SE (changed NS) ..	..	SE
20	SE (changed NS) ..	..	SE

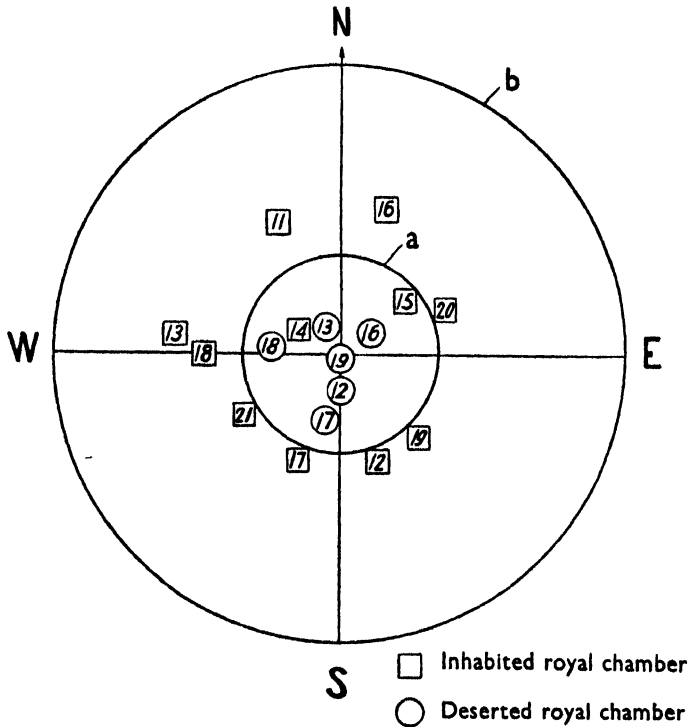
TABLE 9.

*Proportion of axial direction of the queen with reference to magnetic meridian and the direction of the head in *Odontotermes obesus* (Rambur) in Dehra Dun.*

Axial direction	Percentage	
	Queen	Head
NS	0	0
EW	0	0
NW	0	25
NE	25	12.5
SE	75	50
SW	0	12.5

(b) *Location of the royal chamber in reference to mound-sectors and mound-depths.*

Tables 4 and 5 show the position of royal chambers and their proportions with respect to ground-level and the centre of mound. It will be noted (Text-fig. 2)



TEXT-FIG. 2. *Odontotermes obesus* (Rambur). Diagrammatic representation of the position of 'deserted' and 'inhabited' royal chambers in various mounds. Number inside the squares and circles indicates the number of the mound.

a, rim of the central area of mound where fungus combs occur; b, outer edge of mound.

that no particular sector or depth below ground-level can be said to be the most favoured one for this species, and it is felt that the position of the royal chamber might be depending more upon the nature of the ground and other conveniences

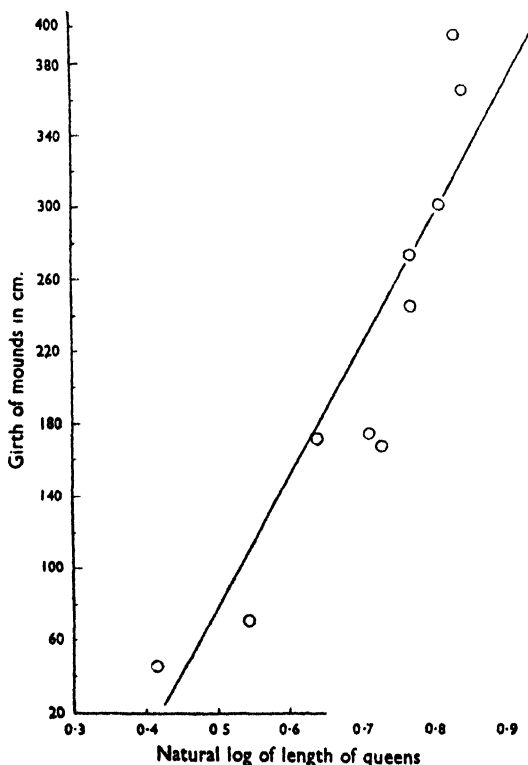
available rather than on any other factor. Deoras (1949) had claimed that the queen lies in the NE sector of the mound (*vide supra*, Introduction).

(c) *Axial direction of the royal chamber and of the queen, and the size of the queen in relation of mound-size.*

Deoras (1949) recorded that in a fungus-growing mound-building termite (name not mentioned, probably *Odontotermes redemanni*, *vide supra*) the queen can be located in the north-east of a mound by placing a strong magnetic compass at its centre and that the queen lies more or less parallel to the magnetic north-south axis.

To test this claim, several mounds of *Odontotermes obesus*, were examined (Tables 6 and 7; and Text-fig. 2) but no directional constancy was found either in the long axis of the royal chamber or of the queen. 64% of the 'inhabited' chambers lie in the NS direction, which may, thus, appear to be the most favoured one. But 67% of the deserted royal chambers, naturally at one time occupied, show directions other than the NS direction. No definiteness, therefore, regarding the most favoured direction of the royal chamber can be seen. The axial directions of the queen (Tables 8 and 9) also do not show any particular relation to the magnetic meridian. Neither does the direction in which the head of the queen lies show any constancy (Table 8). It is, therefore, felt that the assumed correlation of the position of the queen with the magnetic meridian is not established.

The size of the queen has a bearing upon the rate of egg-laying. Therefore, the population of the colony and the size of the mound are evidently related to the size of the queen. Table 3 and Text-fig. 3 show that the size of the queen is directly correlated with mound-girth.



TEXT-FIG. 3. *Odontotermes obesus* (Rambur). Graph showing the relation between the length of queen and mound-girth.

IV. SUMMARY.

1. A study of deserted royal chambers of *Odontotermes obesus* (Rambur), the position of the queen with reference to size and depth of the mound as well as the directional situation of the chambers has been made.

2. It has been found that the queen invariably favours its royal chambers being located in the peripheral regions of the mound. It is, therefore, noticed that in mounds of high girths one often finds a 'deserted' royal chamber in the centre; this was abandoned by the queen which moves to a new chamber in the wall of the mound.

3. The royal chamber is not necessarily carved out at any particular depth or sector of the mound.

4. From the data available it is not possible to establish definitely that the NS direction is the most favoured meridian of the long axis of the royal chamber or of the queen.

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TRANSPORT PROPERTIES OF SOME GAS MIXTURES

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1. INTRODUCTION.

In a recent publication (Srivastava and Madan, 1953a) the force constants for interaction between unlike molecules were found by examining the available data on thermal diffusion and inter-diffusion of gas mixtures. Further from a theoretical investigation of the nature of intermolecular forces it was shown how the force constants for unlike molecules depend upon those for like molecules.

The potential energy function for the molecular interaction which was employed is that of the form

$$E(r) = \lambda r^{-12} - \mu r^{-6} = 4\epsilon [(r_0/r)^{12} - (r_0/r)^6] \quad \dots \quad (1)$$

where λ and μ are the force constants, r is the molecular separation, ϵ the minimum potential energy (taken as positive) and r_0 the distance for which the interaction energy vanishes.

Equations were developed to correlate ϵ_{12} , r_{12} , λ_{12} and μ_{12} for unlike molecules with ϵ_{11} , ϵ_{22} , r_{11} , r_{22} and μ_{11} , μ_{22} , λ_{11} , λ_{22} for like molecules. The previous workers on transport properties of gas mixtures such as Hirschfelder *et al.* (1949), Grew (1949) and Winter (1950) assume the validity of equation (1) and use the experimental data on viscosity and second virial coefficient of gases to obtain the force constants. For the case of binary mixtures they have found it necessary to assume some empirical relation for either ϵ_{12} or r_{12} in order to evaluate these from viscosity, inter-diffusion or virial coefficient data. This is most likely to involve errors of uncertain magnitude. We have therefore adopted a procedure free from this criticism and have utilized the experimental data on thermal diffusion and inter-diffusion for this purpose. It was shown in the previous paper (Srivastava and Madan, 1953a) that our values of ϵ_{12} and r_{12} obtained from experimental data give much better agreement with the theoretical values than the hitherto assumed geometric mean relation for ϵ_{12} and arithmetic mean relation for r_{12} .

In the present paper this method is applied to calculate the other transport properties such as viscosity, and inter-diffusion of gas mixtures and the theoretically calculated values thus obtained are compared with the experimental data. Only such mixtures have been selected for which thermal diffusion data are available and hence the value of ϵ_{12} is known. These have been utilized to calculate r_{12} with the help of the theoretical relations already developed in the previous paper (as inter-diffusion data are generally not available), and the known values of ϵ_{11} and r_{11} for the individual gases.

2. FORMULAE FOR TRANSPORT COEFFICIENTS AND INTERMOLECULAR FORCE CONSTANTS.

The coefficient of viscosity for the case of a binary mixture is given by the relation (Hirschfelder, Bird and Spotz, 1949)

$$\eta_{12} \times 10^7 = \frac{R_1 + R_2 + R_3 + (E/H_1) + (E/H_2)}{(R_1/H_1) + (R_2/H_2) + (E/H_1 H_2) + (R_4/E)} \quad \dots \quad (2)$$

in which

$$R_1 = (x_1/x_2)(2/3 + AM_1/M_2)$$

$$R_2 = (x_2/x_1)(2/3 + AM_2/M_1)$$

$$R_3 = 2[(2/3) - A]$$

$$R_4 = 2A(M_1 + M_2)^2/3M_1M_2$$

$$H_i = 266.93(M_i T)^{1/2}(r_i)^{-2}/W^2(2; kT/\epsilon_i)$$

$$E = 37.75[(M_1 + M_2)^3 T / (M_1 M_2)]^{1/2}(r_{12})^{-2}/W^1(1; kT/\epsilon_{12}).$$

Here x_i is the molefraction of the i th component; M_i is the molecular weight of the i th component; the r_i and r_{12} are the low velocity collision diameters measured in Å; A is a function of the collision integrals W_n^i and is tabulated as a function of kT/ϵ by Hirschfelder *et al.* (1948). The H_i are simply the first approximations to the viscosity of the i th component.

The first approximation for the coefficient of inter-diffusion is given by the relation

$$[D_{12}]_1 = \frac{0.00092916 T^{3/2} [(M_1 + M_2)/M_1 M_2]^{1/2}}{p(r_{12})^2 W^1(1; kT/\epsilon_{12})} \quad \dots \quad (3)$$

in which D_{12} is the coefficient of diffusion in $\text{cm}^2 \text{sec}^{-1}$; p is the pressure in atmospheres and the M_i represent molecular weights. The expression for the second approximation is

$$[D_{12}]_2 = [D_{12}]_1/(1 - \Delta) \quad \dots \quad (4)$$

where Δ is found to be small quantity usually less than 0.03. As the experimental errors in the measurements of D_{12} are of this order, we shall use only the first approximation formulae for D_{12} .

The equation correlating ϵ_{12} , r_{12} with ϵ_{11} , ϵ_{22} and r_{11} , r_{22} is (Srivastava and Madan, 1953a)

$$\epsilon_{12} r_{12}^6 = 2(\epsilon_{11} \epsilon_{22} r_{11}^6 r_{22}^6)^{1/2} (I_1 I_2)^{1/2} / (I_1 + I_2) \quad \dots \quad (5)$$

where I_1 , I_2 are the ionization potentials for individual components.

3. CALCULATION OF TRANSPORT COEFFICIENTS.

The force constants ϵ_{12} employed for the purpose of calculation are given in Table I and are obtained from thermal diffusion. Then equation (5) is used to obtain the force constants r_{12} provided I_1 and I_2 are known. If I_2 , I_1 data are not available the term $2(I_1 I_2)^{1/2} / (I_1 + I_2)$ in equation (5) can be put approximately equal to unity as an actual evaluation of the values (see Table I) shows. When we put this equal to unity, this amounts to assuming a geometric mean relation for the product $\epsilon_{12} r_{12}^6$. Hirschfelder *et al.* (1949), Winter (1950) and others assume that

$$\epsilon_{12} = (\epsilon_{11} \epsilon_{22})^{1/2} \quad \dots \quad (6)$$

and

$$r_{12} = (r_{11} + r_{22})/2 \quad \dots \quad (7)$$

or

$$r_{12} = (r_{11} r_{22})^{1/2} \quad \dots \quad (8)$$

The existence of a geometric mean relation for the product $\epsilon_{12} r_{12}^6$ in no way shows that r_{12} is a geometric mean of r_{11} , r_{22} and ϵ_{12} is a geometric mean of ϵ_{11} , ϵ_{22} . It is true that from the geometric mean relation for ϵ_{12} and r_{12} , equation (5) follows,

but it does not necessarily mean that ϵ_{12} and r_{12} are separately given by geometric mean relations. Our way of calculations is therefore essentially different from that of others and would be identical with theirs only for such formulae, in which ϵ_{12} , r_{12} occur as the product $\epsilon_{12} r_{12}$ ⁶, which is however not the case for any of the transport properties. Equation (7) regarding r_{12} , however seems plausible for hard rigid molecules but will certainly not be applicable in the general case. Likewise the geometric mean rule for ϵ_{12} may apply fairly closely if the two types of molecules have not much different I and r values, but is not true in the general case.

The force constants used for like molecules are those obtained from thermal diffusion (Srivastava and Madan, 1953b), viscosity and second virial coefficient (Hirschfelder *et al.*, 1949) and tabulated in the previous paper (Srivastava and Madan, 1953a), but for the sake of ready reference they are collected in Table II. The ionization potentials of the gases were taken from Margenau (1939). These when substituted in equation (5) yield the values of the force constant r_{12} (see Table I, column 3).

TABLE I.

Force constants for unlike molecules.

Gas Pair	$\epsilon_{12}/k(^{\circ}\text{K})$ from Thermal Diff.	r_{12} (Å) from eq. (5)	$\frac{2(I_1 I_2)^{\frac{1}{2}}}{(I_1 + I_2)}$
H ₂ -N ₂	46.53	3.395	0.9994
H ₂ -O ₂	59.81	3.168	0.9994
H ₂ -A	56.41	3.258	0.9956
H ₂ -CO	52.02	3.345	0.9997
He-A	26.65	3.049	0.9860
Ne-A	56.92	3.170	0.9815
Ne-Kr	62.09	3.311	0.9620
Ne-Xe	69.01	3.485	0.9344
A-Kr	144.1	3.552	0.9959
A-Xe	166.5	3.725	0.9837

TABLE II.

Force constants for like molecules.

Gas	$\epsilon/k(^{\circ}\text{K})$	r_0 (Å)
A	124.0	3.424
O ₂	110.6	3.444
N ₂	87.1	3.701
CO	99.46	3.646
H ₂	33.3	2.968
He	6.03	2.7
Ne	35.7	2.8
Kr	190	3.61
Xe	230	4.051

Utilizing the values of the force constants from Tables I and II and the values of the collision integrals as tabulated by Hirschfelder *et al.* (1948), the values of η_{12} for a number of binary gas mixtures has been calculated with the help of equation (3). These are given in Table III, along with the experimental values for

the gas pairs for which data are available. The experimental binary viscosity data listed are from Landolt-Börnstein, with the single exception of the $\text{H}_2\text{-N}_2$ data (van Itterbeek *et al.*, 1947).

TABLE III. -

Viscosity of Binary Mixtures (in 10^{-7} gm./cm. sec.).

 $\text{H}_2\text{-O}_2$

% H_2	Temp. 300°K		Temp. 400°K	
	Theor.	Exptl.	Theor.	Exptl.
0	2064	2057	2565	2568
18.35	2026	2019	2513	2507
39.45	1945	1925	2405	2381
60.30	1791	1784	2202	2192
78.08	1538	1494	1879	1858
100	887	880	1060	1087

 $\text{H}_2\text{-A}$

% H_2	Temp. 293°K		Temp. 373°K	
	Theor.	Exptl.	Theor.	Exptl.
0	2181	2211	2677	2684
29.42	2100	2140	2560	2586
44.57	2045	2056	2475	2488
65.15	1860	1857	2229	2238
100	872	875	1014	1029

 $\text{H}_2\text{-CO}$

% H_2	Temp. 195°K		Temp. 295°K	
	Theor.	Exptl.	Theor.	Exptl.
0	1253	1264	1740	1745
19.27	1204	1250	1640	1717
40.96	1136	1219	1530	1651
69.47	994	1081	1509	1449
100	664	676	870	874

 He-A

% He	Temp. 293°K		Temp. 373°K	
	Theor.	Exptl.	Theor.	Exptl.
0	2181	2211	2677	2684
38.2	2230	2291	2754	2745
49.06	2239	2296	2761	2750
100	1927	1973	2242	2320

H_2-N_2

% H_2	Temp. 82°K		Temp. 292°K	
	Theor.	Exptl.	Theor.	Exptl.
0	570	544	1766	1746
25.0	570	540	1737	1700
50.0	553	524	1581	1600
75.0	497	493	1328	1396
100	354	362	870	882

Ne-A

% Ne	Temp. 293°K		Temp. 373°K	
	Theor.	Exptl.	Theor.	Exptl.
0	2181	2213	2677	2693
25.8	2365	2401	2859	2885
39.09	2472	2504	2967	2990
73.2	2784	2808	3286	3313
100	3077	3092	3598	3623

Calculated : Viscosities

% *	Ne-Kr Temp. °K		Ne-Xe Temp. °K		A-Kr Temp. °K		A-Xe Temp. °K	
	200	300	200	300	200	300	200	300
0	1719	2523	1546	2310	1719	2523	1546	2310
25.0	1875	2680	1722	2508	1705	2487	1583	2345
50.0	2054	2854	1945	2746	1681	2434	1614	2363
75.0	2245	3026	2206	3004	1645	3360	1625	2369
100	2380	3125	2380	3125	1592	2254	1592	2254

* For Ne-Kr, Ne-Xe read % Ne; and for A-Kr, A-Xe read % A.

Equation (4) shows that a knowledge of the values of the force constants enables us to predict the inter-diffusion coefficient for a binary gas mixture even where no experimental data exist. With the help of Table I and equation (4), this has been done for various temperatures, the values being given in Tables IV and V. For a few gas mixtures experimental values of inter-diffusion coefficient are available (H_2-N_2 , H_2-A : Waldmann, 1944; H_2-N_2 , H_2-O_2 , H_2-CO and He-A: Chapman and Cowling, 1939); these have been compared with the calculated values of D_{12} in Table IV.

TABLE IV.
 D_{12} in $cm.^2 sec.^{-1}$

Gas Pair	Temperature 273.2°K			Temperature 293.2°K	
	Exptl.	Calc. (Present work)	Calc. (Winter)	Exptl.	Calc.
H_2-N_2	0.674	0.653	0.658	0.760	0.736
H_2-O_2	0.697	0.710			
H_2-A				0.770	0.761
H_2-CO	0.651	0.658	0.662		
He-A	0.641	0.639	0.633		

TABLE V.

 D_{12} in $\text{cm}^2 \text{sec}^{-1}$

Gas Pair	Temp. °K			Gas Pair	Temp. °K	
	100	200	300		200	300
H ₂ -N ₂	0.113	0.384	0.764	Ne-A	0.157	0.314
H ₂ -O ₂	0.116	0.414	0.833	Ne-Kr	0.128	0.258
H ₂ -A	0.113	0.395	0.791	Ne-Xe	0.108	0.219
H ₂ -CO	0.112	0.386	0.771	A-Kr	0.064	0.139
He-A	0.117	0.380	0.743	A-Xe	0.052	0.113

4. DISCUSSION OF RESULTS.

It will be seen from Table III that for the gas pairs for which experimental data are available, the agreement between the calculated and experimental viscosities is fairly good, being excellent in certain cases. The slight discrepancies observed in a few cases may be due to slight errors in the assumed values of ϵ_{12} , ϵ_{11} , ϵ_{22} and τ_{12} , τ_{11} , τ_{22} , and the possible errors in the experimental measurements. The deviations from Hirschfelder's calculated (Hirschfelder *et al.*, 1949) values on the assumption of equations (6) and (7) are insignificant and make it impossible to establish the supremacy of one over the other.

No experimental data on viscosity are available for Ne-Kr, Ne-Xe and A-Kr, A-Xe. For this reason the calculated values of viscosities for these pairs of gases cannot be compared with the experimental values. Additional experimental data for these mixtures would be welcome.

A comparison of the calculated and observed values of coefficient of inter-diffusion (see Table IV) shows that the agreement is very good for the gas pairs examined and is somewhat better than that calculated by Winter (1950) using the empirical relations for ϵ_{12} and τ_{12} . Unfortunately a detailed comparison cannot be made for all the gas pairs and also over a wide range of temperatures due to lack of experimental data. This will have to await the determination of D_{12} over a wide range of temperatures for all the gas mixtures.

The above calculations confirm the correctness of the values of the force constants obtained from thermal diffusion and simultaneously provide a satisfactory test of equation (5). Further they provide a good illustration of the use of force constants obtained from one transport property in predicting any desired transport coefficient when no experimental data are available.

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SUMMARY.

Utilizing the intermolecular force constants obtained from thermal diffusion data in conjunction with the theoretical relations connecting these constants for like and unlike molecules developed by us in a previous paper, the transport properties, viz. the coefficients of viscosity and inter-diffusion for a number of binary gas mixtures have been calculated and compared with the experimental results. It is found that the agreement between the theory and the experiment is quite satisfactory.

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THE EXTERNAL FIELD OF A NON-STATIC CENTRALLY SYMMETRIC ISOLATED SYSTEM IN THE UNIFIED FIELD THEORY

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1. INTRODUCTION.

The field equations postulated by Einstein (1950) for the unification of gravitation and electromagnetism are

$$g_{ik,l} - g_{sk}\Gamma_{il}^s - g_{is}\Gamma_{lk}^s = 0 \quad \dots \quad (1.1)$$

$$\Gamma_{is}^s = 0 \quad \dots \quad (1.2)$$

$$R_{ik} = 0 \quad \dots \quad (1.3)$$

where

$$R_{ik} = \Gamma_{ik,s}^s - \frac{1}{2} (\Gamma_{is,k}^s + \Gamma_{sk,i}^s) - \Gamma_{il}^s \Gamma_{sk}^l + \Gamma_{ik}^s \Gamma_{sl}^l,$$

Γ_{ik}^l is a non-symmetric affinity and g_{ik} are the components of a non-symmetric fundamental tensor. The current density in the theory is given by

$$\tilde{S}^s = \frac{1}{2} \epsilon^{ikls} (g_{ik,l} + g_{li,k} + g_{kl,i}) \quad \dots \quad (1.4)$$

with the usual significance for the underlying hook and bar and for ϵ^{ikls} .

These equations for the static spherically symmetric fields were fully solved by Bonner, W. B. (1951 and 1952). Some of the solutions correspond to the continuous distribution of charge. But no solution corresponds to an isolated system containing charge. One expects a solution to exist giving the field of an isolated system containing charge.

Birkhoff's theorem (Tolman 1934) in general relativity is well known. It is worthwhile finding out the analogue of the theorem in a total field theory when the external field is free from matter and charge but not necessarily free from radiation. Generally non-static isolated systems give non-static exterior solutions. Hence to exhaust all the possible spherically symmetric isolated systems we take the field potentials to be non-static and find out the external fields of the existing isolated systems.

It will be difficult to solve (1.1) for Γ_{ik}^l directly. To overcome the difficulty of solving the equations (1.1) we first find out some clues about the independent components of the affine connection.

2. THE FORMS OF g_{ik} AND Γ_{ik}^l FOR SPHERICALLY SYMMETRIC FIELDS.

The condition for spherically symmetric fields is the following: a frame of reference exists such that, after an arbitrary rotation round the centre of symmetry,

the new components \bar{g}_{ik} and $\bar{\Gamma}_{ik}^l$ are the same functions of the new co-ordinates \bar{x}^α as the g_{ik} and Γ_{ik}^l are of x^α respectively. We shall consider infinitesimal point transformations $\bar{x}^\alpha = x^\alpha + \epsilon \xi^\alpha$ in polar co-ordinates. Such a transformation corresponds to an arbitrary rotation round the centre of symmetry in case a sphere, with its centre as centre of symmetry, transforms into itself. That is $\xi^1 = 0$, $\xi^4 = 0$ and ξ^2 and ξ^3 should satisfy the equations of Killing

$$\left. \begin{aligned} \xi^2 \cos \theta + \frac{\partial \xi^3}{\partial \phi} \sin \theta &= 0, \\ \frac{\partial \xi^3}{\partial \theta} \sin^2 \theta + \frac{\partial \xi^2}{\partial \phi} &= 0, \\ \frac{\partial \xi^2}{\partial \theta} &= 0 \end{aligned} \right\} \quad \dots \quad \dots \quad \dots \quad (2.1)$$

Solving (2.1) for ξ^2 and ξ^3 we get

$$\left. \begin{aligned} \xi^2 &= L \cos(\phi + M), \\ \xi^3 &= -L \sin(\phi + M) \cot \theta + N \end{aligned} \right\} \quad \dots \quad \dots \quad \dots \quad (2.2)$$

where L , M and N are arbitrary constants. But L can be made equal to unity by changing ϵ to ϵ' where $\epsilon' = L\epsilon$.

Thus an arbitrary rotation round the centre of symmetry can be defined by the transformation $\bar{x}^\alpha = x^\alpha + \epsilon \xi^\alpha$, where

$$\left. \begin{aligned} \xi^1 &= \xi^4 = 0, \\ \xi^2 &= \cos(\phi + M), \\ \xi^3 &= -\sin(\phi + M) \cot \theta + N. \end{aligned} \right\} \quad \dots \quad \dots \quad \dots \quad (2.3)$$

The conditions of spherical symmetry for g_{ik} and Γ_{ik}^l are

$$\left. \begin{aligned} \bar{g}_{ik} &= g_{ik}(\bar{x}), \\ \bar{\Gamma}_{ik}^l &= \Gamma_{ik}^l(\bar{x}). \end{aligned} \right\} \quad \dots \quad \dots \quad \dots \quad (2.4)$$

Equations (2.4) reduce to the set

$$\left. \begin{aligned} g_{i\sigma} \xi^\sigma_{,k} + g_{\sigma k} \xi^\sigma_{,i} + g_{ik} \xi^\sigma_{,\sigma} &= 0, \\ \Gamma_{ik}^\sigma \xi^\sigma_{,\sigma} - \Gamma_{i\sigma}^\sigma \xi^\sigma_{,k} - \Gamma_{\sigma k}^\sigma \xi^\sigma_{,i} - \Gamma_{ik}^l \xi^\sigma_{,\sigma} - \xi^l_{,ik} &= 0 \end{aligned} \right\} \quad \dots \quad \dots \quad (2.5)$$

Equations (2.5) should be satisfied for arbitrary values of M and N . Some of the components of g_{ik} and Γ_{ik}^l vanish. The remaining components of g_{ik} will be of the form

$$\left. \begin{aligned} g_{11} &= -\alpha \quad ; \quad g_{44} = \gamma \\ g_{23} &= f \sin \theta \quad ; \quad g_{14} = \omega \\ g_{22} &= g_{33} \operatorname{cosec}^2 \theta = -\beta \\ g_{14} &= a \end{aligned} \right\} \quad \dots \quad \dots \quad \dots \quad (2.6)$$

and

where α , β , γ , f , ω and a are functions of r and t ,

The non-vanishing components of Γ_{ik}^i consist of the following :—

$$\left. \begin{aligned} & \Gamma_{11}^1; \Gamma_{14}^1; \Gamma_{14}^1; \Gamma_{22}^1; \Gamma_{44}^1; \Gamma_{12}^2; \Gamma_{12}^2 \\ & \Gamma_{44}^4; \Gamma_{41}^4; \Gamma_{41}^4; \Gamma_{22}^4; \Gamma_{11}^4; \Gamma_{42}^2; \Gamma_{42}^2 \\ & \Gamma_{23}^1 \operatorname{cosec} \theta; \Gamma_{13}^2 \operatorname{cosec} \theta; \Gamma_{13}^2 \operatorname{cosec} \theta \\ & \Gamma_{23}^4 \operatorname{cosec} \theta; \Gamma_{43}^2 \operatorname{cosec} \theta; \Gamma_{43}^2 \operatorname{cosec} \theta \end{aligned} \right\} \dots \dots \dots (2.7)$$

which are twenty functions of r and t only ;

$$\Gamma_{23}^3 = \cot \theta, \Gamma_{33}^2 = -\sin \theta \cos \theta, \dots \dots \dots (2.8)$$

which are functions of θ only and the rest as given by

$$\left. \begin{aligned} & \Gamma_{33}^1 = \Gamma_{22}^1 \sin^2 \theta; \Gamma_{33}^4 = \Gamma_{22}^4 \sin^2 \theta \\ & \Gamma_{12}^3 = -\Gamma_{13}^2 \operatorname{cosec}^2 \theta; \Gamma_{42}^3 = -\Gamma_{43}^2 \operatorname{cosec}^2 \theta \\ & \Gamma_{12}^3 = -\Gamma_{13}^2 \operatorname{cosec}^2 \theta; \Gamma_{42}^3 = -\Gamma_{43}^2 \operatorname{cosec}^2 \theta \\ & \Gamma_{13}^3 = \Gamma_{12}^2; \Gamma_{13}^3 = \Gamma_{12}^2; \Gamma_{43}^3 = \Gamma_{42}^2; \Gamma_{43}^3 = \Gamma_{42}^2 \end{aligned} \right\} \dots \dots \dots (2.9)$$

By a non-singular (r, t) transformation we reduce g_{14} to zero and g_{22} to $(-r^2)$ Hence the form of g_{ik} may be taken as

$$\left. \begin{aligned} & g_{11} = -\alpha; g_{44} = \gamma \\ & g_{23} = f \sin \theta; g_{14} = \omega \\ & g_{22} = g_{33} \operatorname{cosec}^2 \theta = -\beta = -r^2 \end{aligned} \right\} \dots \dots \dots (2.10)$$

3. SOLUTIONS OF THE FIELD EQUATIONS IN EMPTY SPACE.

Making use of (2.8), (2.9) and (2.10) we solve the equations (1.1) for the twenty components of Γ_{ik}^i which are given in (2.7). We find the non-vanishing Γ_{ik}^i as follows :

$$\left. \begin{aligned} & \Gamma_{11}^1 = \frac{\alpha'}{2\alpha}; \Gamma_{14}^1 = \frac{\omega}{2\alpha} \psi'; \Gamma_{44}^4 = \frac{\dot{\gamma}}{2\gamma}; \Gamma_{41}^4 = \frac{\omega}{2\gamma} \dot{\psi} \\ & \Gamma_{14}^1 = \frac{\omega^2}{2\alpha\gamma} \dot{\psi} + \frac{\dot{\alpha}}{2\alpha}; \Gamma_{41}^4 = \frac{\omega^2}{2\alpha\gamma} \psi' + \frac{\gamma'}{2\gamma} \\ & \Gamma_{44}^1 = \frac{\omega^2}{\alpha^2} \psi' + \frac{\gamma'}{2\alpha}; \Gamma_{11}^4 = \frac{\omega^2}{\gamma^2} \dot{\psi} + \frac{\dot{\alpha}}{2\gamma} \\ & \Gamma_{22}^1 = \Gamma_{33}^1 \operatorname{cosec}^2 \theta = \frac{Bf - \beta A}{2\alpha}; \Gamma_{22}^4 = \Gamma_{33}^4 \operatorname{cosec}^2 \theta = -\frac{Df - \beta C}{2\gamma} \end{aligned} \right\} \dots (3.1)$$

$$\left. \begin{aligned} \Gamma_{23}^1 &= \frac{fA + \beta B}{2\alpha} \sin \theta; \quad \Gamma_{23}^4 = -\frac{fC + \beta D}{2\gamma} \sin \theta \\ \Gamma_{12}^2 &= \Gamma_{13}^3 = \frac{1}{2} A; \quad \Gamma_{42}^2 = \Gamma_{43}^3 = \frac{1}{2} C \\ \Gamma_{12}^2 &= \Gamma_{13}^3 = \frac{\omega C}{2\gamma}; \quad \Gamma_{42}^2 = \Gamma_{43}^3 = \frac{\omega A}{2\alpha} \\ \Gamma_{13}^2 &= -\Gamma_{12}^3 \sin^2 \theta = \frac{\omega D}{2\gamma} \sin \theta; \quad \Gamma_{43}^2 = -\Gamma_{42}^3 \sin^2 \theta = \frac{\omega B}{2\alpha} \sin \theta \\ \Gamma_{13}^2 &= -\Gamma_{12}^3 \sin^2 \theta = \frac{1}{2} B \sin \theta; \quad \Gamma_{43}^2 = -\Gamma_{42}^3 \sin^2 \theta = \frac{1}{2} D \sin \theta \end{aligned} \right\} \dots (3.1)$$

where

$$\left. \begin{aligned} A &= \frac{\beta\beta' + ff'}{\beta^2 + f^2}; \quad C = \frac{\beta\dot{\beta} + f\dot{f}}{\beta^2 + f^2} \\ B &= \frac{f\beta' - \beta f'}{\beta^2 + f^2}; \quad D = \frac{f\dot{\beta} - \beta\dot{f}}{\beta^2 + f^2} \\ \psi &= \log \left(1 - \frac{\alpha\gamma}{\omega^2} \right) \end{aligned} \right\} \dots \dots \dots (3.2)$$

and an overhead dot and an overhead dash denote a differentiation with respect to t and r respectively.

Substituting for Γ_{ik}^l from (3.1) in equations (1.2) we get

$$\left. \begin{aligned} -\frac{\omega}{\alpha} \left[\frac{1}{2} \dot{\psi}' - A \right] &= 0, \\ -\frac{\omega}{\gamma} \left[\frac{1}{2} \dot{\psi} - C \right] &= 0. \end{aligned} \right\} \dots \dots \dots (3.3)$$

Equations (1.3) give

$$\begin{aligned} R_{11} &= -A' - \frac{1}{2}(A^2 + B^2) + \frac{A\alpha'}{2\alpha} + \Gamma_{14}^4 \left(\frac{\alpha'}{2\alpha} - \Gamma_{14}^4 \right) - \Gamma_{14,1}^4 \\ &\quad + \Gamma_{11,4}^4 + \Gamma_{11}^4 \left(\frac{\dot{\gamma}}{2\gamma} - \Gamma_{14}^1 + C \right) + \frac{\omega^2}{2\gamma^2} (C^2 + D^2) + \frac{\omega^2}{4\gamma^2} (\dot{\psi})^2 = 0, \quad \dots (3.4) \end{aligned}$$

$$\begin{aligned} R_{44} &= -\dot{C} - \frac{1}{2}(C^2 + D^2) + \frac{C\dot{\gamma}}{2\gamma} + \Gamma_{41}^1 \left(\frac{\dot{\gamma}}{2\gamma} - \Gamma_{41}^1 \right) - \Gamma_{41,4}^1 \\ &\quad + \Gamma_{44,1}^1 + \Gamma_{44}^1 \left(\frac{\alpha'}{2\alpha} - \Gamma_{41}^4 + A \right) + \frac{\omega^2}{2\alpha^2} (A^2 + B^2) + \frac{\omega^2}{4\alpha^2} (\psi')^2 = 0, \quad \dots (3.5) \end{aligned}$$

$$\begin{aligned} R_{22} &= R_{33} \operatorname{cosec}^2 \theta = \left[\frac{fB - \beta A}{2\alpha} \right]' + \frac{(fB - \beta A)}{4\alpha} \cdot \frac{\partial}{\partial r} [\log (\omega^2 - \alpha\gamma)] \\ &\quad + \frac{B(fA + \beta B)}{2\alpha} + 1 - \frac{\partial}{\partial t} \left[\frac{fD - \beta C}{2\gamma} \right] - \frac{(fD - \beta C)}{4\gamma} \cdot \frac{\partial}{\partial t} [\log (\omega^2 - \alpha\gamma)] \\ &\quad - \frac{D(fC + \beta D)}{2\gamma} = 0, \quad \dots \dots \dots (3.6) \end{aligned}$$

$$R_{23} \operatorname{cosec} \theta = \left[\frac{fA + \beta B}{2\alpha} \right]' + \frac{(fA + \beta B)}{4\alpha} \left[\frac{\alpha'}{\alpha} + 2\Gamma_{14}^4 \right] - \frac{B(fB - \beta A)}{2\alpha} \\ - \frac{\partial}{\partial t} \left[\frac{fC + \beta D}{2\gamma} \right] - \frac{(fC + \beta D)}{4\gamma} \left[\frac{\dot{\gamma}}{\gamma} + 2\Gamma_{41}^1 \right] + \frac{D(fD - \beta C)}{2\gamma} = 0, \quad (3.7)$$

$$R_{14} = \Gamma_{14,1}^1 + \frac{\omega}{2\alpha} (A^2 + B^2) + A \Gamma_{14}^1 - \Gamma_{41,4}^4 - \frac{\omega}{2\gamma} (C^2 + D^2) - C \Gamma_{41}^4 = 0, \quad (3.8)$$

$$R_{14} = \frac{1}{2} (\Gamma_{14,1}^1 + \Gamma_{41,4}^4) - \frac{1}{2} (\Gamma_{11,4}^1 + \Gamma_{44,1}^4) - (\Gamma_{12,4}^2 + \Gamma_{42,1}^2) \\ + 2\Gamma_{14}^1 \Gamma_{12}^2 + 2\Gamma_{41}^4 \Gamma_{42}^2 + \Gamma_{14}^1 \Gamma_{41}^4 + \Gamma_{14}^1 \Gamma_{41}^4 - \Gamma_{11}^1 \Gamma_{44}^4 - 2\Gamma_{12}^2 \Gamma_{42}^2 \\ + 2\Gamma_{12}^2 \Gamma_{42}^2 + 2\Gamma_{13}^2 \Gamma_{43}^2 \operatorname{cosec}^2 \theta - 2\Gamma_{13}^2 \Gamma_{43}^2 \operatorname{cosec}^2 \theta = 0. \quad \dots \quad (3.9)$$

The current density in empty space surrounding the isolated system is zero. Hence we get

$$\left. \begin{aligned} \tilde{S}^1 &\equiv -f \sin \theta = 0, \\ \tilde{S}^4 &\equiv f^1 \sin \theta = 0, \\ \tilde{S}^2 &\equiv \tilde{S}^3 = 0. \end{aligned} \right\} \dots \dots \dots (3.10)$$

Using (3.10) and (3.3) in (3.9) it is found that

$$R_{14} = \frac{\dot{\alpha}}{2\alpha} A \left(1 - \frac{\omega^2}{\alpha\gamma} \right) = 0. \quad \dots \quad (3.11)$$

Using (3.3), (3.10) and (3.11) and simplifying the equations (3.4), (3.5), (3.6), (3.7), and (3.8) we get

$$R_{11} = -A' - \frac{1}{2} (A^2 + B^2) + \frac{A\alpha'}{2\alpha} + \Gamma_{14}^4 \left(\frac{\alpha'}{2\alpha} - \Gamma_{14}^4 \right) - \Gamma_{14,1}^4 = 0, \quad \dots \quad (3.12)$$

$$R_{44} = \Gamma_{44,1}^1 + \Gamma_{44}^1 \left(\frac{\alpha'}{2\alpha} - \Gamma_{14}^4 + A \right) + \frac{\omega^2}{2\alpha^2} (A^2 + B^2) + \frac{\omega^2}{4\alpha^2} (\psi')^2 = 0, \quad \dots \quad (3.13)$$

$$R_{22} = R_{33} \operatorname{cosec}^2 \theta = \left[\frac{fB - \beta A}{2\alpha} \right]' + \frac{(fB - \beta A)}{4\alpha} \cdot \frac{\partial}{\partial r} [\log (\omega^2 - \alpha\gamma)] \\ + B \frac{(fA + \beta B)}{2\alpha} + 1 = 0, \dots \quad (3.14)$$

$$R_{23} \operatorname{cosec} \theta = \left[\frac{fA + \beta B}{2\alpha} \right]' + \frac{(fA + \beta B)}{4\alpha} \left[\frac{\alpha'}{\alpha} + 2\Gamma_{14}^4 \right] - \frac{B(fB - \beta A)}{2\alpha} = 0, \quad (3.15)$$

$$R_{14} = \Gamma_{14,1}^1 + \frac{\omega}{2\alpha} (A^2 + B^2) + A \Gamma_{14}^1 = 0 \quad \dots \quad (3.16)$$

From (3.12) and (3.13) we have

$$\frac{1}{\alpha} R_{11} + \frac{1}{\gamma} R_{44} = A \left(1 - \frac{\omega^2}{\alpha\gamma} \right) \frac{\partial}{\partial r} \left\{ \log \left[\frac{\omega^2 - \alpha\gamma}{A^2 \beta} \right] \right\} = 0 \quad \dots \quad (3.17)$$

Computing (3.14) and (3.15) we get

$$\left[\frac{fA + \beta B}{fB - \beta A} \right]' - B \left[1 + \left(\frac{fA + \beta B}{fB - \beta A} \right)^2 \right] - \frac{2\alpha(fA + \beta B)}{(fB - \beta A)^2} = 0.$$

Using (2.10), (3.2) and (3.10) in the above equation we get

$$\left[\frac{2fr^2}{f^2 - r^4} \right]' - \frac{2fr(f^2 + r^4)}{(f^2 - r^4)^2} - \frac{2fr(f^2 + r^4)}{(f^2 - r^4)^2} \cdot \alpha = 0 \quad \dots \quad (3.18)$$

But

$$\left[\frac{2fr^2}{f^2 - r^4} \right]' = \frac{4fr(f^2 + r^4)}{(f^2 - r^4)^2}.$$

Hence (3.18) gives

$$\alpha = 1. \quad \dots \quad (3.19)$$

For the consistency of (3.15), (3.17) and (3.19) $fr^2(9f + r^4)/(f^2 + r^4)^2$ should be equal to zero which means that

$$f = 0 \quad \dots \quad (3.20)$$

Then (3.15) satisfies identically. Equations (3.17) and (3.19) give

$$\omega^2 - \alpha\gamma = c_2 \quad \dots \quad (3.21)$$

where c_2 is independent of r . But applying the boundary conditions we get

$$c_2 = -1 \quad \dots \quad (3.22)$$

Substituting for $(\omega^2 - \alpha\gamma)$ from (3.21) in (3.14) we get

$$\alpha = \left[1 - \frac{2m}{r} \right]^{-1} \quad \dots \quad (3.23)$$

where m is independent of r . But from (3.11) it should not be a function of t , which means that m is a constant. Equations (3.3) under (3.20) give two alternatives

$$(1) \quad \omega = 0,$$

$$(2) \quad 1 - \frac{\alpha\gamma}{\omega^2} = c_1\beta^2,$$

where c_1 is a constant.

CASE 1. $\omega = 0$

Field equations reduce to the equations of general relativity. Hence we get Swartzschild's exterior solution.

CASE 2. $\omega \neq 0$

Then from (3.3) we get

$$1 - \frac{\alpha\gamma}{\omega^2} = c_1\beta^2 \quad \dots \quad (3.24)$$

Using (3.20), (3.21), (3.23), (3.24) in (3.16) we get

$$\frac{2m}{r^5} = 0,$$

which means that

$$m = 0 \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (3.25)$$

Hence the complete solution is

$$\left. \begin{aligned} \alpha &= 1, \beta = r^2, \\ \gamma &= 1 - l^2/r^4, \\ \omega &= \pm \sqrt{-1} \, l/r^2, f = 0, \end{aligned} \right\} \quad \dots \quad \dots \quad (3.26)$$

where

$$l = \left(\frac{1}{c_1} \right)^{\frac{1}{2}}.$$

4. EXAMINATION OF THE SOLUTIONS.

When $\omega = 0$ we get the isolated system containing mass that is an inertial particle only. But when $\omega \neq 0$ we get the solution (3.26) which corresponds to the isolated magnetic pole. But this contains no mass. Solution (3.26) does not correspond to an isolated charge particle because the integral for the charge enclosed between $r = r_1$ and $r = r_2$ is to be identified with the corresponding integral in electrostatics. That is

$$\int_{r_1}^{r_2} \int_0^\pi \int_0^{2\pi} \tilde{S}^4 \, dr \, d\theta \, d\phi = \pm \frac{1}{4\pi} \int_{r_1}^{r_2} \int_0^\pi \int_0^{2\pi} \nabla^2 \Phi \cdot r^2 \sin \theta \, dr \, d\theta \, d\phi,$$

where Φ is the potential in electrostatics. This means that f/r^2 is to be identified with the electric intensity and hence ω with the magnetic intensity only.

Here it may be noted that Einstein and Straus equations give the solution when $\omega \neq 0$

$$\begin{aligned} \alpha &= \left(1 - \frac{2m}{r} \right)^{-1}, \quad \gamma = \left(1 - \frac{2m}{r} \right) (1 - l^2/r^4), \\ \beta &= r^2, \quad \omega = \pm \sqrt{-1} \, l/r^2, \\ f &= 0, \end{aligned}$$

where l and m are constants.

While the earlier theory makes it possible for an isolated magnetic pole to have mass the new theory makes it impossible. This is a distinct improvement in the new theory.

5. CONCLUSION.

For the theory to be complete, identification of a vector density with the current density should be made. Electric current density in the unified field theory is given by the vector density \tilde{S}^s . If there is no alternative identification, the theory makes it impossible for the isolated spherically symmetric system to be associated with charge. Even though we make it possible for the system to be non-static, there are no corresponding external solutions for the solutions we get for the empty space, surrounding the isolated system, are static. If there exist a centrally symmetric non-static isolated system, the field equations considered by us do not favour its existence.

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ABSTRACT.

This work has arisen out of Bonner's work on static spherically symmetrical fields in the unified field theory as revised by Einstein in 1950. It is found that here also there is a result corresponding to Birkhoff's theorem in general relativity. There exists no non-static spherically symmetrical solution of the unified field equations in space which is free from matter and charge. The interesting feature of the investigation is that it shows clearly how certain features of the total field can exist in isolation but not together.

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THE INERTIAL FIELD OF A CHARGE PARTICLE

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1. INTRODUCTION

The nature of interaction of gravitational and electromagnetic fields is studied with reference to a particular case, that of a charge particle. One expects that the unified field equations should be such that when the electromagnetic field is totally absent, the equations provide a pure gravitational field and *vice versa*. This expectation was not realized for the field equations of the unified field theory recently proposed by Einstein (1950). The gravitational deflexion of light which has been experimentally established and the suspected connection between a rotating field of matter and magnetic field, suggest that a pure electromagnetic field will have an associated inertial field. Our calculations show that Einstein's equations testify to this. In the unified field theory of Einstein there is a tensor g_{ik} which consists of two parts :

$$g_{ik} = \underline{g}_{ik} + g_{ik}$$

so that

$$\underline{g}_{ik} = \underline{g}_{ki}, \quad g_{ik} = -g_{ki}.$$

The bar and the hook are used under pairs of suffixes to denote symmetry and anti-symmetry respectively. The contravariant tensor is given by

$$g_{ik}g^{ok} = g_{ki}g^{ko} = \delta_i^o.$$

We have taken into consideration the two possibilities of adopting \underline{g}_{ik} or s_{ik} as the gravitational metric, the latter being suggested by Schrödinger (1948) and defined in such a way that its determinant s and the contravariant tensor s^{ik} are given by

$$s = \text{Det. } g^{ik}, \quad \sqrt{-s} s^{ik} = \sqrt{-g} g^{ik}, \quad g^{ik} = \sqrt{-g} g^{ik}.$$

We have also considered the alternatives regarding the interpretations of g_{14} and g_{23} of the electromagnetic field.

The field equations of Einstein's unified theory in their strongest form (1950) are :

$$g_{ik,l} - g_{sk} \Gamma_{il}^s - g_{is} \Gamma_{lk}^s = 0, \quad \dots \dots \dots (1.1)$$

$$\Gamma_{is}^s = 0, \quad \dots \dots \dots (1.2)$$

$$R_{ik} \equiv \Gamma_{ik,s}^s - \frac{1}{2} \left(\Gamma_{is,k}^s + \Gamma_{sk,i}^s \right) - \Gamma_{it}^s \Gamma_{sk}^t + \Gamma_{ik}^s \Gamma_{st}^t = 0. \quad \dots (1.3)$$

The three index symbols are defined by (1.1) and they reduce to the Chrystoffel symbols when $g_{ik} = 0$.

For a charge particle, the field is static and spherically symmetric. The polar form of static, spherically symmetric g_{ik} is given by

$$g_{11} = -\alpha, \quad g_{22} = -\beta, \quad g_{33} = -\beta \sin^2 \theta, \quad g_{44} = \gamma,$$

$$g_{14} = -g_{41} = \omega, \quad g_{23} = -g_{32} = f \sin \theta;$$

the other $g_{\mu\nu}$ components vanish and α, β, γ, f and ω are functions of r only.

For the field of a charge particle either ω or f/r^2 should be identified as the electric intensity.

2. THE CASE WHEN f/r^2 IS ELECTRIC INTENSITY.

If f/r^2 is identified as the electric intensity, we may take

$$\omega = 0, \quad f/r^2 = e/r^2.$$

When (1.1) is solved for Γ_{ik}^l , the only non-vanishing Γ_{ik}^l are given as follows:

$$\left. \begin{aligned} \Gamma_{11}^1 &= \frac{\alpha'}{2\alpha}, \quad \Gamma_{22}^1 = \operatorname{cosec}^2 \theta \Gamma_{33}^1 = \frac{eB - \beta A}{2\alpha}, \\ \Gamma_{23}^1 &= \frac{(eA + \beta B)}{2\alpha} \sin \theta, \quad \Gamma_{44}^1 = \frac{\gamma'}{2\alpha}, \\ \Gamma_{12}^2 &= \Gamma_{13}^3 = \frac{1}{2} A, \quad \Gamma_{13}^2 = -\Gamma_{12}^3 \sin^2 \theta = \frac{1}{2} B \sin \theta, \\ \Gamma_{33}^2 &= -\sin \theta \cos \theta, \quad \Gamma_{23}^3 = \cot \theta, \\ \Gamma_{14}^4 &= \frac{\gamma'}{2\gamma}, \end{aligned} \right\} \quad (2.1)$$

where

$$A = \frac{\beta\beta'}{e^2 + \beta^2}, \quad B = \frac{e\beta'}{e^2 + \beta^2};$$

and the overhead dash denotes differentiation with respect to r .

We find that (1.2) is satisfied identically and (1.3) gives:

$$R_{11} = -\frac{(\beta\beta')'}{e^2 + \beta^2} - \frac{1}{2} \frac{\beta'^2}{(e^2 + \beta^2)} + \frac{\alpha'}{2\alpha} \frac{\beta\beta'}{(e^2 + \beta^2)} + \Gamma_{14}^4 \left(\frac{\alpha'}{2\alpha} - \Gamma_{14}^4 \right) - \Gamma_{14,1}^4 = 0, \quad \dots \quad (2.2)$$

$$R_{22} = \operatorname{cosec}^2 \theta R_{33} = \left(\frac{eB - \beta A}{2\alpha} \right)' + (eB - \beta A) \frac{(\log \alpha\gamma)^2}{4\alpha} + \frac{B(eA + \beta B)}{2\alpha} + 1 = 0, \quad \dots \quad (2.3)$$

$$R_{23} \operatorname{cosec} \theta = \left(\frac{eA + \beta B}{2\alpha} \right)' + \frac{(eA + \beta B)}{4\alpha^2} \left(\alpha' + 2\alpha \Gamma_{14}^4 \right) - \frac{B(eB - \beta A)}{2\alpha} = 0, \quad \dots \quad (2.4)$$

$$R_{44} = \Gamma_{44,1}^1 + \Gamma_{44}^1 \left(\frac{\alpha'}{2\alpha} - \Gamma_{14}^4 + A \right) = 0. \quad \dots \quad (2.5)$$

Equations (2.3) and (2.4) are simplified to :

$$(e^2 - \beta^2) \left[\beta'' - \frac{\beta'}{2} \left(\frac{\alpha'}{\alpha} - \frac{\gamma'}{\gamma} \right) \right] - 2e\beta \frac{e\beta'^2}{e^2 + \beta^2} + 2\alpha(e^2 + \beta^2) = 0, \quad \dots (2.6)$$

$$2e\beta \left[\beta'' - \frac{\beta'}{2} \left(\frac{\alpha'}{\alpha} - \frac{\gamma'}{\gamma} \right) \right] + (e^2 - \beta^2) \frac{e\beta'^2}{e^2 + \beta^2} = 0. \quad \dots (2.7)$$

From these we get :

$$\beta'^2 = 4\alpha\beta, \quad \dots (2.8)$$

$$\beta'' - \frac{\beta'}{2} \left(\frac{\alpha'}{\alpha} - \frac{\gamma'}{\gamma} \right) + 2\alpha \cdot \frac{e^2 - \beta^2}{e^2 + \beta^2} = 0. \quad \dots (2.9)$$

We get, on simplification,

$$\beta' \left[\frac{\beta'e^2}{\beta(e^2 + \beta^2)} + \frac{\gamma'}{2\gamma} \right] = 0. \quad \dots (2.10)$$

But $\beta' = 0$ gives :

$$\alpha = 0$$

or

$$\beta = 0$$

which cannot happen :

hence

$$\frac{\beta'e^2}{\beta(e^2 + \beta^2)} + \frac{\gamma'}{2\gamma} = 0. \quad \dots (2.11)$$

Equation (2.5) gives :

$$\frac{\gamma'^2}{\alpha\gamma} (e^2 + \beta^2) = c_1 \quad \dots (2.12)$$

where c_1 is a constant of integration.

From (2.8), (2.11) and (2.12)

$$\left. \begin{aligned} -8e^2\gamma' &= c_1\beta' \\ \gamma &= -\frac{c_1\beta}{8e^2} + c_2 \end{aligned} \right\} \dots (2.13)$$

Substituting for γ and γ' from (2.13) in (2.11) we have that either

$$\beta' = 0$$

or

$$c_2 - \frac{3c_1\beta}{16e^2} = \frac{c_1\beta^3}{16e^4},$$

both of which mean that

$$\beta' = 0.$$

It means that there exists no solution when f/r^2 is identified as the electric intensity.

3. THE CASE WHEN ω IS ELECTRIC INTENSITY

Now considering the second alternative, that of identifying ω as the electric intensity, we take

$$f = 0, \quad \omega = e/r^2 \quad \dots (3.1)$$

The values of non-vanishing Γ_{ik}^l are then, as follows:—

$$\left. \begin{aligned} \Gamma_{11}^1 &= \frac{\alpha'}{2\alpha}, \quad \Gamma_{22}^1 = \operatorname{cosec}^2\theta \quad \Gamma_{33}^1 = -\frac{\beta'}{2\alpha}, \\ \Gamma_{14}^1 &= \frac{\omega}{2\alpha} \left[\log \left(1 - \frac{\alpha\gamma}{\omega^2} \right) \right]', \\ \Gamma_{44}^1 &= \frac{4\omega\omega'\alpha\gamma - 2\omega^2\alpha'\gamma - (\omega^2 + \alpha\gamma)\alpha\gamma'}{2\alpha^2(\omega^2 - \alpha\gamma)}, \\ \Gamma_{12}^2 &= \Gamma_{13}^3 = \frac{1}{2} \frac{\beta'}{\beta}, \quad \Gamma_{33}^2 = -\sin\theta \cos\theta, \\ \Gamma_{24}^2 &= \Gamma_{34}^3 = -\frac{\omega}{2\alpha} \frac{\beta'}{\beta}, \quad \Gamma_{23}^3 = \cot\theta, \\ \Gamma_{14}^4 &= \frac{2\omega\omega'\alpha - \omega^2\alpha' - \alpha^2\gamma'}{2\alpha(\omega^2 - \alpha\gamma)} \end{aligned} \right\} \quad \dots \quad (3.2)$$

Equation (1.2) gives:—

$$\left[\log \left(1 - \frac{\alpha\gamma}{\omega^2} \right) \right]' = \frac{2\beta'}{\beta}. \quad \dots \quad (3.3)$$

Hence,

$$\left(1 - \frac{\alpha\gamma}{\omega^2} \right) = c_1 \beta^2, \quad \dots \quad (3.4)$$

where c_1 is the constant of integration.

Using (3.2) in (3.3), we have:

$$\Gamma_{14}^1 = \frac{\omega}{\alpha} \frac{\beta'}{\beta}. \quad \dots \quad (3.5)$$

Equation (1.3) reduce to:

$$R_{11} = -\left(\frac{\beta'}{\beta}\right)' - \frac{1}{2}\left(\frac{\beta'}{\beta}\right)^2 + \frac{1}{2}\frac{\beta'\alpha'}{\beta\alpha} + \Gamma_{14}^1\left(\frac{\alpha'}{2\alpha} - \Gamma_{14}^1\right) - \Gamma_{11,1}^4 = 0, \quad \dots \quad (3.6)$$

$$R_{22} = \operatorname{cosec}^2\theta R_{33} = -\left(\frac{\beta'}{2\alpha}\right)' - \frac{\beta'}{2\alpha}\left(\frac{\beta'}{\beta} + \frac{\omega'}{\omega}\right) + 1 = 0, \quad \dots \quad (3.7)$$

$$R_{44} = \Gamma_{44,1}^1 + \frac{3}{2}\frac{\beta'^2}{\beta^2}\frac{\omega^2}{\alpha^2} + \Gamma_{44}^1\left(\frac{\alpha'}{2\alpha} - \Gamma_{14}^1 + \frac{\beta'}{\beta}\right) = 0, \quad \dots \quad (3.8)$$

$$R_{14} = \left(\frac{\omega\beta'}{\alpha\beta}\right)' + \omega\frac{\beta'^2}{2\beta^2\alpha} + \frac{\beta'}{\beta}\frac{\omega\beta'}{\beta\alpha} = 0. \quad \dots \quad (3.9)$$

From (3.9) we get:

$$\frac{\omega'\beta'}{\alpha\beta} + \frac{\omega\beta''}{\alpha\beta} - \frac{\omega\beta'(\alpha\beta' + \alpha'\beta)}{\alpha^2\beta^2} + \frac{3\omega\beta'^2}{2\beta^2\alpha} = 0$$

or

$$\frac{\alpha'}{\alpha} = \frac{\omega'}{\omega} + \frac{\beta''}{\beta'} + \frac{1}{2}\frac{\beta'}{\beta}.$$

Integrating we get :

$$\alpha = c_2 \omega \beta' \beta^{\frac{1}{2}} \quad \dots \quad \dots \quad \dots \quad (3.10)$$

where c_2 is a constant.

Equation (3.7) gives :

$$-\frac{\beta''}{2\alpha} + \frac{\beta'\alpha'}{2\alpha^2} - \frac{\beta'^2}{2\alpha\beta} - \frac{\beta'}{2\alpha} \frac{\omega'}{\omega} + 1 = 0.$$

Substituting for α from (3.10) and simplifying, we get :

$$-\frac{\beta''}{\beta'} + \frac{\alpha'}{\alpha} - \frac{\beta'}{\beta} - \frac{\omega'}{\omega} + 2c_2\omega\beta^{\frac{1}{2}} = 0$$

or

$$\left[\log \frac{\alpha}{\beta\beta'\omega} \right]' = -2c_2\omega\beta^{\frac{1}{2}}.$$

Further, on account of (3.10)

$$-\frac{1}{2} \frac{\beta'}{\beta^{\frac{3}{2}}} = -2c_2 \frac{e}{r^2}.$$

Integrating we obtain :

$$\beta = \left(2c_2 \frac{e}{r} + c_3 \right)^{-2} \quad \dots \quad \dots \quad \dots \quad (3.11)$$

and hence, from (3.10),

$$\alpha = 4c_2^2 \frac{e^2}{r^4} \left(2c_2 \frac{e}{r} + c_3 \right)^{-4} \quad \dots \quad \dots \quad \dots \quad (3.12)$$

From (3.4), (3.10) and (3.12) we get :

$$\gamma = \frac{e^2}{r^4 \alpha} - \frac{c_1}{4c_2^2} \quad \dots \quad \dots \quad \dots \quad (3.13)$$

These values of α , β and γ satisfy (3.6) and (3.8) also. Thus, the equations (3.11–3.13) provide the exact solution of the field equations in this case.

For the metric g_{ik} , the boundary conditions imposed are :

$$\alpha \rightarrow 1, \frac{\beta}{r^2} \rightarrow 1, \gamma = 1 \text{ as } r \rightarrow \infty.$$

From (3.12)

$$\alpha = 4 c_2^2 e^2 (2c_2 e + c_3 r)^{-4}$$

If $c_3 \neq 0$,

$$\alpha \rightarrow 0 \text{ as } r \rightarrow \infty.$$

Therefore

$$c_3 = 0.$$

Then from (3.11)

$$\frac{\beta}{r^2} = (2c_2 e)^{-2}$$

But, as $\frac{\beta}{r^2} \rightarrow 1$

$$2c_2e = \pm 1,$$

and hence

$$\alpha = 1.$$

Also, for $\gamma \rightarrow 1$ as $r \rightarrow \infty$, we get from (3.13)

$$-\frac{c_1}{4c_2^2} = 1,$$

So

$$\gamma = \frac{e^2}{r^4} + 1.$$

Thus

$$\left. \begin{aligned} \alpha &= 1 \\ \beta &= r^2 \\ \gamma &= 1 + \frac{e^2}{r^4} \end{aligned} \right\} \quad \dots \quad \dots \quad \dots \quad \dots \quad (3.14)$$

Hence the gravitational metric is :

$$ds^2 = -dr^2 - r^2(d\theta^2 + \sin^2\theta d\phi^2) + \left(1 + \frac{e^2}{r^4}\right) dt^2.$$

4. ENERGY DISTRIBUTION

We now proceed to find the energy distribution in space.

First, we take $\underline{g_{ik}}$ as the metric given by

$$g_{11} = -1, \quad g_{22} = -r^2, \quad g_{33} = -r^2 \sin^2\theta, \quad g_{44} = 1 + \frac{e^2}{r^4},$$

and all other components vanish.

The Einstein tensor R'_{ik} is defined in terms of the Chrystoffel three-index symbols, the latter being calculated for the metric tensor g_{ik} in the first case and for s_{ik} in the second case.

$$R'_{11} = \frac{6e^2}{r^6 \left(1 + \frac{e^2}{r^4}\right)} + \frac{4e^2}{r^6 \left(1 + \frac{e^2}{r^4}\right)^2},$$

$$R'_{22} = R'_{33} \operatorname{cosec} \theta = -\frac{2e^2}{r^4 \left(1 + \frac{e^2}{r^4}\right)},$$

$$R'_{44} = -\frac{2e^2}{r^6} - \frac{4e^2}{\left(1 + \frac{e^2}{r^4}\right)r^6};$$

Hence

$$R'_1 = -\frac{6e^2}{r^6\left(1+\frac{e^2}{r^4}\right)} - \frac{4e^2}{r^6\left(1+\frac{e^2}{r^4}\right)^2},$$

$$R'_2 = R'_3 = \frac{2e^2}{r^6\left(1+\frac{e^2}{r^4}\right)},$$

$$R'_4 = -\frac{2e^2}{r^6\left(1+\frac{e^2}{r^4}\right)} - \frac{4e^2}{r^6\left(1+\frac{e^2}{r^4}\right)^2},$$

and so

$$R' = -\frac{4e^2}{r^6\left(1+\frac{e^2}{r^4}\right)} - \frac{8e^2}{r^6\left(1+\frac{e^2}{r^4}\right)^2}.$$

Now

$$G_\mu^\nu = R'_\mu{}^\nu - \frac{1}{2}\delta_\mu^\nu R' = -8\pi T_\mu^\nu;$$

therefore

$$G_1^1 = -\frac{4e^2}{r^6\left(1+\frac{e^2}{r^4}\right)}, \quad G_1^4 = 0,$$

and

$$G_2^2 = G_3^3 = \frac{4e^2}{r^6\left(1+\frac{e^2}{r^4}\right)} + \frac{4e^2}{r^6\left(1+\frac{e^2}{r^4}\right)^2},$$

whence

$$G = \frac{4e^2\left(3+\frac{e^2}{r^4}\right)}{r^6\left(1+\frac{e^2}{r^4}\right)^2}$$

and

$$T = -\frac{1}{2\pi} \frac{e^2\left(3+\frac{e^2}{r^4}\right)}{r^6\left(1+\frac{e^2}{r^4}\right)^2}.$$

There is the other choice, that of taking s_{ik} as the gravitational metric, as suggested by Schrödinger. It is given by

$$s = \text{Det. } g^{ik}, \quad \sqrt{-s} s^{ik} = \sqrt{-g} g^{ik}, \quad g^{ik} = \sqrt{-g} g^{ik}.$$

Here

$$g_{11} = -\alpha, \quad g_{22} = -\beta, \quad g_{33} = -\beta \sin^2\theta, \quad g_{44} = \gamma, \quad g_{14} = -g_{41} = \omega,$$

and all other g_{ik} components vanish. As regards s_{ik} we have

$$s_{11} = -\alpha \left(1 - \frac{\omega^2}{\alpha\gamma}\right)^{\frac{1}{2}}, \quad s_{22} = -\beta \left(1 - \frac{\omega^2}{\alpha\gamma}\right)^{-\frac{1}{2}},$$

$$s_{33} = -\beta \sin^2\theta \left(1 - \frac{\omega^2}{\alpha\gamma}\right)^{-\frac{1}{2}}, \quad s_{44} = \gamma \left(1 - \frac{\omega^2}{\alpha\gamma}\right)^{\frac{1}{2}},$$

all other components vanishing. The boundary conditions are as follows :

$$\alpha \left(1 - \frac{\omega^2}{\alpha\gamma}\right)^{\frac{1}{2}} \rightarrow 1, \quad \frac{\beta}{r^2} \left(1 - \frac{\omega^2}{\alpha\gamma}\right)^{-\frac{1}{2}} \rightarrow 1,$$

$$\gamma \left(1 - \frac{\omega^2}{\alpha\gamma}\right)^{\frac{1}{2}} \rightarrow 1 \quad \text{as } r \rightarrow \infty,$$

which means that α , $\frac{\beta}{r^2}$ and γ all tend to 1.

Hence we have ultimately

$$s_{11} = -\left(1 + \frac{e^2}{r^4}\right)^{-\frac{1}{2}}, \quad s_{22} = -r^2 \left(1 + \frac{e^2}{r^4}\right)^{\frac{1}{2}},$$

$$s_{33} = -r^2 \sin^2\theta \left(1 + \frac{e^2}{r^4}\right)^{\frac{1}{2}}, \quad s_{44} = \left(1 + \frac{e^2}{r^4}\right)^{\frac{1}{2}},$$

all other components vanishing.

Then, we get :

$$R'_{11} = -\frac{3e^2 \left(3 + \frac{e^2}{r^4}\right)}{r^6 \left(1 + \frac{e^2}{r^4}\right)^2},$$

$$R'_{22} = R'_{33} \operatorname{cosec}^2\theta = 0,$$

$$R'_{44} = \frac{3e^2}{r^6}.$$

Hence

$$R'_1 = \frac{3e^2 \left(3 + \frac{e^2}{r^4}\right)}{r^6 \left(1 + \frac{e^2}{r^4}\right)^{\frac{3}{2}}},$$

$$R'_2 = R'_3 = 0,$$

$$R'_4 = \frac{3e^2}{r^6 \left(1 + \frac{e^2}{r^4}\right)^{\frac{1}{2}}};$$

and so

$$R' = \frac{6e^2 \left(2 + \frac{e^2}{r^4}\right)}{r^6 \left(1 + \frac{e^2}{r^4}\right)^{\frac{3}{2}}}.$$

From

$$G_{\mu}^{\nu} = R_{\mu}^{\nu} - \frac{1}{2} \delta_{\mu}^{\nu} R' = -8\pi T_{\mu}^{\nu}$$

$$G_1^1 = -\frac{3e^2}{r^6 \left(1 + \frac{e^2}{r^4}\right)^{\frac{3}{2}}}, \quad G_4^4 = -\frac{3e^2}{r^6 \left(1 + \frac{e^2}{r^4}\right)^{\frac{3}{2}}},$$

$$G_2^2 = G_3^3 = -\frac{3e^2 \left(2 + \frac{e^2}{r^4}\right)}{r^6 \left(1 + \frac{e^2}{r^4}\right)^{\frac{3}{2}}};$$

whence

$$G = -\frac{6e^2 \left(2 + \frac{e^2}{r^4}\right)}{r^6 \left(1 + \frac{e^2}{r^4}\right)^{\frac{3}{2}}}$$

and

$$T = \frac{3}{4\pi} \frac{e^2 \left(2 + \frac{e^2}{r^4}\right)}{r^6 \left(1 + \frac{e^2}{r^4}\right)^{\frac{3}{2}}}.$$

5. DISCUSSION

The field equations of the unified theory of Einstein (1950) are such that when the electromagnetic field is switched off we get the case of pure gravitation. So, one expects that when the gravitational field is absent, we get the case of a pure electromagnetic field. But when we considered a simpler case of a static and spherically symmetric electromagnetic field in flat space, we found that the electromagnetic field components necessarily vanish. This suggested that there is an inevitable inertial field associated with, at least, the static and spherically symmetric electromagnetic field. So we considered the field of a charge particle with the general spherically symmetric tensor g_{ik} . We first identified g_{23} as the source

of electric intensity according to the new convention suggested by Einstein and Schrödinger. We found that there exists no solution in this case. But when g_{14} is identified as the electric intensity, we got an exact solution.

Next, we proceeded to find the energy distribution in space. As there is no obvious way for the choice of the gravitational metric in this theory, we calculated T for both cases (1) when g_{ik} is the gravitational metric and (2) when s_{ik} , as

defined above, is the gravitational metric. The energy distribution in space is found to be weaker than in the classical theory.

The conclusions that we arrive at are the following :

- (1) g_{14} describes the electric intensity and g_{23} is the source of magnetic intensity.
- (2) The electromagnetic field of a charge particle carries with it an inertial field distributed throughout the space which cannot be transformed away.

We are indebted to Professor V. V. Narlikar for his valuable guidance in preparing this note.

ABSTRACT

The electromagnetic field of a charge particle is considered with the general spherically symmetric tensor in polar form with reference to Einstein's equations of a unified field theory. The alternatives of identifying g_{14} or g_{23} as the source of electric field intensity are explored.

One of the conclusions arrived at is that g_{14} and not g_{23} is the source of electric intensity.

The solution of the unified field equations gives a metric for a charge particle the mechanical energy for which is obtained by using the equations of classical general relativity. The energy distribution so determined is found to be weaker than that given by Nordström's solution of the gravitational field of a charge particle in general relativity.

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RADIAL OSCILLATIONS OF A COMPOSITE MODEL

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1. INTRODUCTION

Nearly all the stellar models considered these days are composite, in the sense that they consist of a core and an envelope under different conditions of equilibrium. A composite model of utmost simplicity is the generalized Roche's model, introduced in astronomical investigations by Jeans (1919). This consists of a homogeneous core of finite extent and density, surrounded by an envelope of finite extent but infinitesimal density. The radial oscillations of this model were considered by Sen (1943), and more recently by Kopal (1950). For considerations of mathematical simplicity, they supposed that the density in the envelope, though infinitesimal, varies inversely as the square of the distance from the centre of the star.

It was pointed out, however, by Cowling (1947) that Sen's investigation was invalid, as it did not consider the most general motion securing continuity of motion at the interface between the envelope and the core. Kopal's investigation, though valid inasmuch as it secures the continuity of motion across the interface, suffers from an unnecessary restriction. More general solutions, employing hypergeometric expansions starting from the surface of the star, could be obtained.*

The pressure exerted on the core by an envelope of infinitesimal density is negligible. This imposes an additional restriction on the radial oscillations of the generalized Roche's model. In fact, this model requires a node at the interface as well as at the surface of the star. Other models (composite or otherwise) in which the pressure of the envelope is not negligible do not suffer from this restriction. For this reason it is more convenient to take a composite model consisting of a homogeneous core surrounded by an envelope of small uniform density. This model was introduced by the author (1944) in a paper discussing its configurations of rotation.

The anharmonic pulsations of this model have been considered by Bhatnagar (1945), who also determines the period of small oscillation. But in his investigations, Bhatnagar assumes the amplitude of oscillation to be constant throughout the star. Because of this the period of oscillation obtained by him is the same as the approximate period obtained by the method of Ledoux and Pekeris (1941). For the same reason his conclusions regarding the anharmonic pulsations are open to doubt, more so as he disregards the modes of oscillation other than the fundamental.

The present paper considers the small adiabatic radial oscillations of this very model, consisting of a homogeneous compressible core surrounded by an envelope of small uniform density. It is found that it is not at all necessary to place restrictions on the ratios of the densities and the radii of the core and the envelope or on

* This was pointed by the author in a private communication to Dr. Kopal, who acknowledged that 'the conditions enumerated in his paper though sufficient for the existence of a solution of the prescribed type, were not also the necessary conditions'.

the ratio of the specific heats of the material. In fact, the model is capable of performing radial oscillations whatever be the values of these ratios. The amplitudes and the periods of oscillation in the first three modes have been determined for five cases, with different ratios of the densities and radii. It is seen that the amplitudes do not remain constant throughout the star as supposed by Bhatnagar (1945). They increase considerably in the envelope for the fundamental mode of oscillation.

2. EQUATION FOR THE CORE

The differential equation for small adiabatic radial oscillation of a star is (Rosseland, 1949)

$$\frac{d^2\eta}{dr_0^2} + \frac{4-\mu}{r_0} \frac{d\eta}{dr_0} + \left(\frac{n^2\rho_0}{\gamma P_0} - \frac{\alpha\mu}{r_0^2} \right) \eta = 0, \quad \dots \quad (1)$$

where η is the amplitude of the relative displacement $\delta r_0/r_0$; $\mu = g_0\rho_0 r_0/P_0$, g_0 , ρ_0 , P_0 being respectively the equilibrium values of gravity, density and pressure at a distance r_0 from the centre; $\alpha = 3-4/\gamma$, γ being the effective ratio of specific heats; and $n = 2\pi\nu$, where ν is the frequency of oscillation. The boundary conditions require the solution to be non-singular both at the centre and the surface of the star.

Let us take a model consisting of a compressible core of uniform density ρ , surrounded by an envelope of uniform density σ ; and suppose that the radius of the core is bR , that of the whole star being R . Then, at any point of the core, we have

$$g_0 = GM(r_0)/r_0^2 = \frac{4}{3} \pi G \rho r_0,$$

and

$$P_0 = \int g_0 \rho_0 dr_0 = P_i + \frac{2}{3} \pi G \rho^2 (b^2 R^2 - r_0^2), \quad \dots \quad (2)$$

where the constant of integration has been so adjusted that the pressure at the interface, $r_0 = bR$, is P_i .

Putting $r_0 = Rx$, and taking

$$k^2 = b^2 + P_i \left(\frac{2}{3} \pi G \rho^2 R^2 \right), \quad \dots \quad (3)$$

we can write

$$P_0 = \frac{2}{3} \pi G \rho^2 R^2 (k^2 - x^2),$$

so that

$$\mu = \frac{2x^2}{k^2 - x^2} \quad \text{and} \quad \frac{n^2\rho_0}{\gamma P_0} = \frac{3n^2}{2\pi G \rho R^2} \cdot \frac{1}{k^2 - x^2}.$$

Substituting these in equation (1), we get

$$(k^2 - x^2) \frac{d^2\eta}{dx^2} + \frac{4k^2 - 6x^2}{x} \frac{d\eta}{dx} + J\eta = 0, \quad \dots \quad (4)$$

where

$$J = \frac{3n^2}{2\pi G \rho R^2} - 2\alpha. \quad \dots \quad (5)$$

This gives the amplitude η at any point of the core.

A solution in series is possible. The roots of the indicial equation are 0 and -3. Taking the former to avoid a singularity at the origin, we get

$$\eta = a_0 + a_2 \left(\frac{x}{k}\right)^2 + a_4 \left(\frac{x}{k}\right)^4 + \dots, \quad \dots \quad (6)$$

where

$$a_{2j+2} = a_{2j} \frac{4j^2 + 10j - J}{(2j+2)(2j+5)}, \quad \dots \quad (7)$$

Since $\lim a_{2j+2}/a_{2j}$ is unity, the power series (6) is convergent for x less than k , whatever be the value of J . Now the relation (3) shows that b is less than k . Therefore the series for η converges at every point of the core and also at the interface, whatever the frequency of oscillation.*

It may be noted in passing that equation (4) is same as the equation of oscillation for a homogeneous star, only now the radius of convergence is k instead of unity.

3. EQUATION FOR THE ENVELOPE

At any point of the envelope, we have

$$\begin{aligned} g_0 &= GM(r_0)/r_0^2 \\ &= G \left\{ \frac{4}{3} \pi \rho b^3 R^3 + \frac{4}{3} \pi \sigma (r_0^3 - b^3 R^3) \right\} / r_0^2 \\ &= \frac{2}{3} \pi G \sigma R \{ 2x + K/x^2 \}, \end{aligned}$$

where

$$K = 2 \left(\frac{\rho - \sigma}{\sigma} \right) b^3, \quad \dots \quad (8)$$

and $x = r_0/R$. Also,

$$P_0 = - \int g_0 \rho_0 dr_0 = \frac{2}{3} \pi G \sigma^2 R^2 \left\{ 1 - x^2 + K \left(\frac{1}{x} - 1 \right) \right\} \quad \dots \quad (9)$$

where the constant of integration has been so adjusted that the pressure is zero at the surface of the star, $x = 1$.

With these values, we get

$$\mu = \frac{K + 2x^3}{K + (1-K)x - x^3}$$

and

$$\frac{n^2 \rho_0}{\gamma P_0} = \frac{3n^2}{2\pi G \gamma \sigma R^2} \cdot \frac{x}{K + (1-K)x - x^3}.$$

Substituting in (1), the equation for oscillation becomes

$$\{ K + (1-K)x - x^3 \} \frac{d^2 \eta}{dx^2} + \frac{3K + 4(1-K)x - 6x^3}{x} \frac{d\eta}{dx} + (J'x^3 - K\alpha) \frac{\eta}{x^2} = 0, \quad \dots \quad (10)$$

where

$$J' = \frac{3n^2}{2\pi G \gamma \sigma} - 2\alpha. \quad \dots \quad (11)$$

* This is not true for the model considered by Sen and Kopal.

This equation has regular singularities at $x = 0$ and $x = 1$. A solution in series starting from one extremity will, in general, diverge at the other extremity. Since we require a solution finite at $x = 1$, but not extending to the centre, we put the substitution $x = 1-t$ in (10). Then it becomes

$$t(1-t)^2(K+2-3t+t^2) \frac{d^2\eta}{dt^2} + (1-t)\{K+2-(4K+14)t+18t^2-6t^3\} \frac{d\eta}{dt} + \{J'-K\alpha-3J't+3J't^2-J't^3\}\eta = 0 \quad \dots \quad (12)$$

A solution in series of the form

$$\eta = c_0 + c_1 t + c_2 t^2 + c_3 t^3 + \dots \quad (13)$$

can be obtained, in which the coefficients are connected by the relations:

$$(K+2)c_1 + (J'-K\alpha)c_0 = 0,$$

$$4(K+2)c_2 - (5K+16+K\alpha-J')c_1 - 3J'c_0 = 0,$$

$$9(K+2)c_3 - (14K+46+K\alpha-J')c_2 + (4K+32-3J')c_1 + 3J'c_0 = 0,$$

$$16(K+2)c_4 - (27K+90+K\alpha-J')c_3 + (10K+82-3J')c_2 - (24-3J')c_1 - J'c_0 = 0,$$

etc., and in general by

$$\begin{aligned} n^2(K+2)c_n - [(n-1)\{(2n+1)K+7n+2\} + K\alpha-J']c_{n-1} \\ + [(n-2)\{(n+1)K+9n+5\} - 3J']c_{n-2} \\ - [(n-3)(5n+4) - 3J']c_{n-3} \\ + [(n-4)(n+1) - J']c_{n-4} = 0. \quad \dots \quad (14) \end{aligned}$$

It can be verified that no singularity of equation (12) lies within a circle of unit radius. Therefore the series (13) converges at every point of the envelope, whatever be the frequency of oscillation.

4. BOUNDARY CONDITIONS AT THE INTERFACE

We have seen above that the usual boundary conditions of non-singularity of the amplitude at the centre and the surface are satisfied by our solutions for the core and the envelope respectively, for all frequencies of oscillation. The particular frequency in which a star will oscillate is now determined from the condition that the motion should be continuous across the interface.

The continuity of motion requires that $\delta r_0/r_0$ and $\delta P_0/P_0$ should both have the same values on the two sides of the interface at any instant. This will be so, provided η and η' both are continuous across the interface.

In practice it is found more convenient to ensure the continuity of η'/η across the interface, since η'/η is independent of the constant of integration. The continuity of η can then be ensured by adjusting the constants a_0 and c_0 .

We shall now give the value of k in terms of b and σ/ρ . From (9) we have

$$P_i = \frac{2}{3} \pi G \sigma^2 R^2 \left\{ 1 - b^2 + K \left(\frac{1}{b} - 1 \right) \right\}.$$

Substituting this in (3), we get

$$k^2 = b^2 + \left(\frac{\sigma}{\rho} \right)^2 \left\{ 1 - b^2 + K \left(\frac{1}{b} - 1 \right) \right\}. \quad \dots \quad (15)$$

5. SOLUTION OF THE EQUATIONS

Numerical solution has been carried out for five cases with different values of b and ρ/σ , and the periods and amplitudes obtained for the first three modes of oscillation. Table 1 gives the values of $T\sqrt{(G\rho/6\pi)}$ for these modes, where T is the period of oscillation. For comparison, the periods of oscillation for the homogeneous model are also given. Tables 2 and 3 give the amplitudes of oscillation. The figure below will give some idea of the variation of the amplitude in the star.

TABLE 1.

$T\sqrt{(G\rho/6\pi)}$ for composite models ($\gamma = 5/3$).

Model	0th mode	1st mode	2nd mode	T/T_1
I. $b = 0.3, \rho/\sigma = 40$	0.5122	0.1701	0.1363	3.01
II. $b = 0.3, \rho/\sigma = 20$ .. ..	.5589	.1820	.1418	3.07
III. $b = 0.3, \rho/\sigma = 10$ .. ..	.6123	.1924	.1434	3.18
IV. $b = 0.5, \rho/\sigma = 10$ .. ..	.5024	.2302	.1375	2.18
V. $b = 0.7, \rho/\sigma = 10$ .. ..	.4936	.2499	.1231	1.98
Homogeneous	0.7071	0.1987	0.1270	3.56

TABLE 2.

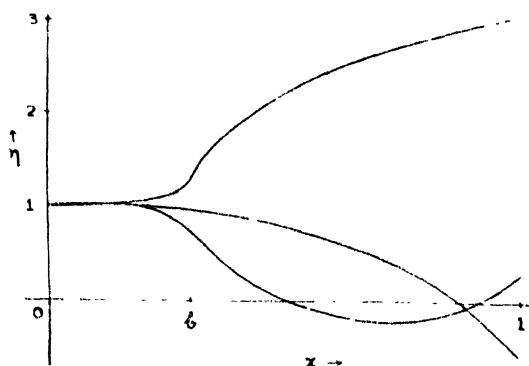
η for the composite models.

Model	I. $b = 0.3, \rho/\sigma = 40$			II. $b = 0.3, \rho/\sigma = 20$			III. $b = 0.3, \rho/\sigma = 10$		
mode x	0th	1st	2nd	0th	1st	2nd	0th	1st	2nd
0.00	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
.05	1.003	1.000	0.999	1.003	1.000	0.998	1.002	0.998	0.994
.10	1.012	1.002	.995	1.011	0.998	.989	1.010	.992	.977
.15	1.030	1.004	.988	1.028	.996	.973	1.023	.982	.946
.20	1.062	1.008	.975	1.056	.991	.946	1.046	.964	.895
.25	1.124	1.015	.951	1.110	.983	.897	1.086	.934	.811
.30	1.383	1.045	.857	1.281	.959	.757	1.178	.868	.649
.35	2.208	1.137	.556	1.631	.906	.478	1.312	.775	.415
.40	2.794	1.195	.344	1.880	.863	.283	1.408	.705	.252
.45	3.241	1.222	.183	2.069	.820	.137	1.479	.613	.130
.50	3.602	1.220	0.055	2.221	.771	0.024	1.537	.583	0.036
.55	3.905	1.189	— 0.048	2.346	.713	— 0.065	1.584	.520	— 0.037
.60	4.167	1.126	— .130	2.455	.642	— .132	1.625	.453	— .092
.65	4.406	1.026	— .191	2.550	.557	— .178	1.661	.380	— .129
.70	4.617	0.886	— .228	2.636	.457	— .203	1.691	.299	— .149
.75	4.817	0.700	— .240	2.713	.338	— .204	1.719	.208	— .150
.80	5.003	0.463	— .219	2.784	.199	— .178	1.744	0.109	— .130
.85	5.180	0.168	— .158	2.852	0.038	— .120	1.767	— 0.001	— .088
.90	5.350	— 0.192	— 0.048	2.915	— 0.143	— 0.027	1.788	— 0.122	— 0.018
.95	5.512	— 0.623	0.120	2.975	— 0.365	0.109	1.809	— 0.253	0.080
1.00	5.667	— 1.135	0.359	3.030	— 0.590	0.291	1.828	— 0.396	0.210
J'	3.496	41.40	65.08	1.707	26.19	43.96	0.789	18.96	35.10

TABLE 3.

 η for the composite models.

Model	IV. $b = 0.5, \rho/\sigma = 10$			V. $b = 0.7, \rho/\sigma = 10$		
mode x	0th	1st	2nd	0th	1st	2nd
0.00	1.000	1.000	1.000	1.000	1.000	1.000
.05	1.001	0.999	0.996	1.000	0.999	0.993
.10	1.003	.996	.982	1.000	.995	.971
.15	1.006	.990	.962	1.001	.988	.935
.20	1.011	.982	.926	1.002	.978	.885
.25	1.018	.970	.867	1.003	.966	.821
.30	1.027	.954	.800	1.004	.949	.743
.35	1.041	.932	.714	1.005	.929	.651
.40	1.060	.901	.599	1.007	.904	.546
.45	1.092	.852	.433	1.010	.872	.428
.50	1.162	.751	0.137	1.013	.833	.297
.55	1.277	.590	0.295	1.017	.781	.155
.60	1.377	.449	-0.636	1.023	.712	0.003
.65	1.464	.322	-0.893	1.032	.605	0.155
.70	1.545	.201	-1.035	1.053	0.378	.303
.75	1.609	0.085	-1.048	1.096	-0.052	.386
.80	1.668	0.032	-0.956	1.138	0.474	.411
.85	1.724	.150	-0.677	1.180	0.896	.353
.90	1.816	.271	0.191	1.222	1.324	0.178
.95	1.875	.396	0.545	1.263	1.764	0.155
1.00	1.932	0.526	1.581	1.304	2.221	0.697
J'	3.850	22.88	66.19	8.871	38.06	160.6



Variation of amplitude for Model II.

The solutions are obtained by trial and error. The values of η'/η at the interface are obtained for the core and the envelope for two different frequencies, and the correct frequency of oscillation inferred from them by interpolation. The values of η'/η are recalculated for this frequency and a better approximation to the frequency obtained by interpolating again. The process is repeated if necessary. It is expected that the solutions are accurate to three figures at least.

In all the cases the solution in series is used to find the value of η'/η for the core. For the envelope the series solution is used for the cases $b = 0.5$ and 0.7 , while for the case $b = 0.3$ a numerical integration of the equations is effected to extend the solution up to 0.3 .

6. CONCLUSIONS

The cases considered above have been chosen to provide two sequences of models. The models I-III provide a sequence with a fixed interface (at $b = 0.3$) and decreasing values of ρ/σ , while the models III-V provide a sequence with a fixed ratio of densities ($\rho/\sigma = 10$) and increasing values of b .

The models of the first sequence show a marked similarity and gradation in their oscillations. The period of oscillation increases regularly with decreasing central condensation for all the modes. The amplitude of the fundamental oscillation shows a rapid increase in the envelope, this increase becoming less for decreasing central condensation. The amplitudes of the higher modes, however, show the characteristic of the homogeneous model: having a smaller amplitude at the surface than at the centre (except for the case $\rho/\sigma = 40$).

The models of the second sequence do not show such a marked similarity or gradation. The periods of the 0th and the 2nd mode of oscillation decrease while the period of the 1st mode increases with increasing b . The decrease in the period of the fundamental mode of oscillation indicates an increasing central condensation. This is not apparent from the ratio of the central to mean density which is 8.05 , 4.71 and 2.45 respectively, for these models. But if we calculate for these models the ratio of the mass contained within three-fourths of the radius, say, to the total mass, we get 0.535 , 0.728 and 0.859 respectively, thus proving our contention.

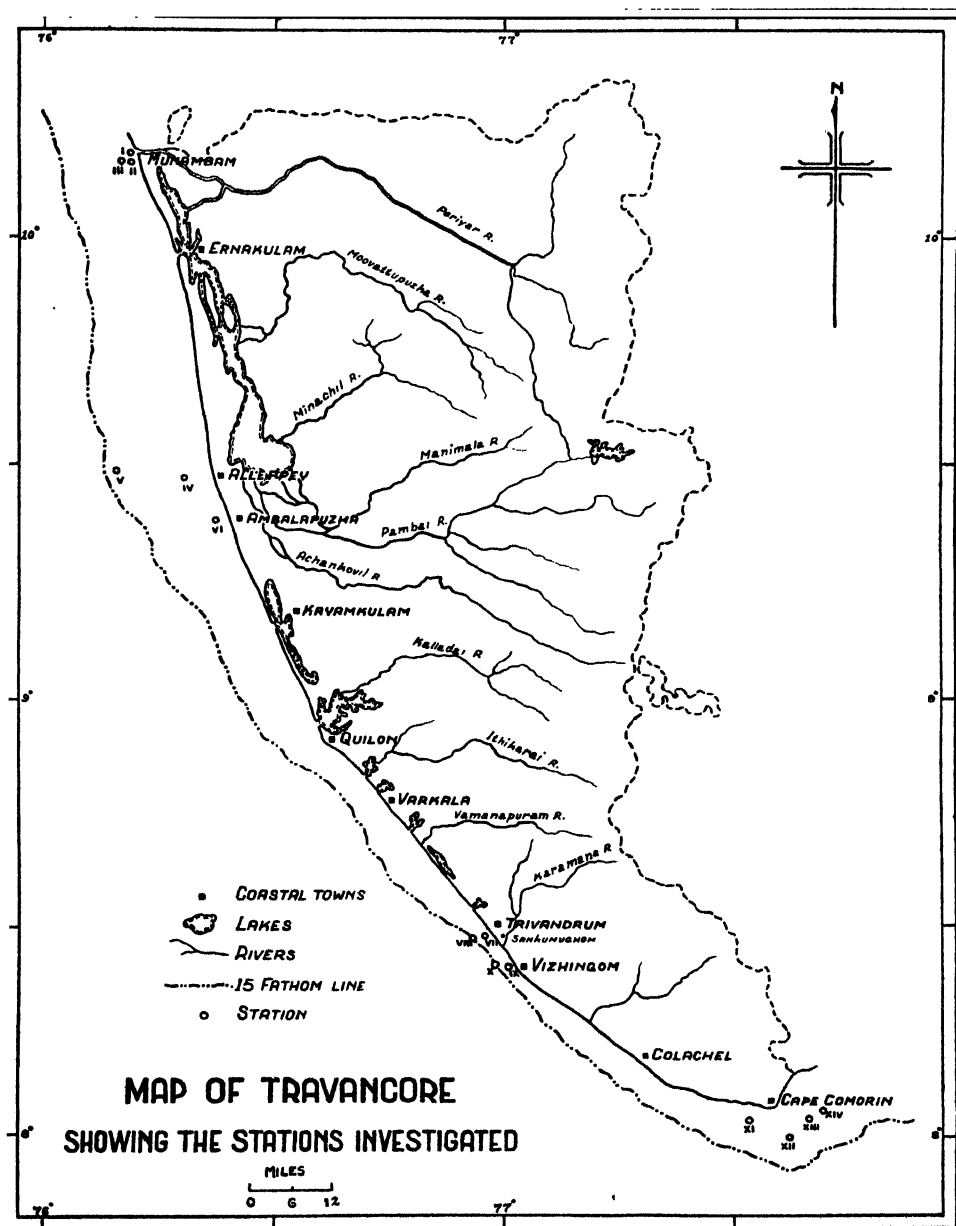
The main point to notice is the ratio of the period of the fundamental mode to that of the first overtone. By a suitable choice of the parameters b and ρ/σ , this ratio can be made nearly 2 or even less than 2, as for the models IV and V. The anharmonic pulsations of such models will be interesting to consider as they are expected to show a fair resonance and a considerable skewness of the radial velocity curve.

ABSTRACT

Radial oscillations of a composite model consisting of a homogeneous compressible core surrounded by an envelope of small uniform density are considered, and the period and amplitude of oscillation in the first three modes obtained for five cases with different ratios of the densities and radii. Considering the most general motion, it is shown that it is not at all necessary to place restrictions on these ratios as found previously by other investigators. It is also shown that by a suitable choice of these ratios it is possible to obtain a model for which the period of the fundamental mode is less than twice the period of the first overtone.

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A PRELIMINARY SURVEY OF THE BOTTOM FAUNA AND BOTTOM DEPOSITS OF THE TRAVANCORE COAST WITHIN THE 15-FATHOM LINE

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INTRODUCTION

The valuable researches of Allen (1899), Stephen (1929 and 1930), Elmhirst (1931) and Crawford (1937*a* and *b*), have shown that the distribution of the animals which live at the sea bottom depends mainly on the 'physical and biological conditions' to which they are subjected. Allen is also of opinion that 'the external biological conditions affecting the distribution of a species in any locality are themselves largely, if not entirely, due to physical conditions acting in the same or in neighbouring localities'.

It has been observed by Marion (1883) in the Gulf of Marseilles, Petersen (1889-1893) in the Kattegat, Herdman (1887-1898) in the Irish Sea, Pruvot (1897) in the Mediterranean and in Brittany, and Watkin (1942) in Kames Bay, Buteshire, that the nature of the 'Bottom Fauna' changes in accordance with the character of the 'Bottom Deposit', especially in shallow waters. The same authors have observed that the texture of the deposit has greater importance than its geological character, in its relation to the fauna living upon it.

It is generally recognized that a detailed knowledge of the conditions of the sea bottom and the nature of the animals which live in it is essential for determining whether a particular area is suitable for fishing. The complete absence of such information has been a great handicap to the development of the fishing industry

in India on modern lines. So, the Department of Marine Biology and Fisheries of the University of Travancore took up this problem as part of their programme of sea fisheries investigation. As no motor fishing vessel was available, it was decided to start work by employing ordinary dug-out canoes used by local fishermen for inshore fishing. These frail crafts are not meant to work in the open sea nor are they large enough to carry all the necessary equipment. The present survey has therefore been confined to the inshore regions within a distance of two to three miles from the Coast, very often not beyond the fifteen fathom limit. The observations recorded in this paper are restricted only to a general study of the bottom-dwelling organisms found within this region and to their distribution in relation to the nature of the deposits.

MATERIAL AND METHOD

The materials described in this paper have been collected from various localities along the Travancore Coast from September, 1943 to August, 1946. Fourteen stations, most of them in the neighbourhood of important fishing centres were selected between Cape Comorin in the extreme south and Munambom, the northern boundary of the State (Ref. Map). It will be seen that these stations are in four groups, of which the first three are in the extreme north and the last four in the extreme south. In between these, are seven stations in two groups, more or less equidistant from the two ends. The regions marked by these four groups of stations represent the important fishing centres of the State, and the conditions which prevail there give more or less a general idea of the adjoining regions also.

At least four collections were taken from each station with an iron dredge 1' 7" \times 10" weighing 25 lbs. This dredge was used for collecting the bottom fauna as well as the bottom deposits. For collecting the bottom fauna, a fine conical net was tied to the dredge, while for collecting the bottom deposit an internal lining of canvas was also attached. In regions where the ground was firm and smooth a small beam trawl of 6 ft. beam was employed for collecting the bottom-feeding fishes and other larger organisms, while in places suspected to be rocky a grab of $\frac{3}{4}$ c. ft. capacity was first tried for testing the nature of the ground.

Though the survey was originally planned to extend up to the 15-fathom line, it was found in practice that this line which was often 10 to 15 miles from shore could not always be reached in the small canoes or catamarans. Thus for example the maximum depth reached at Munambom was only 8 fathoms. At Alleppey where a motor tug was available it was possible to make collections from 15 miles offshore.

The present survey of the bottom fauna is mainly of a qualitative nature, but at Trivandrum an attempt was made to study the seasonal and zonal distribution of some of the common bottom-dwelling organisms.

In all cases, the collections were brought ashore for examination. The larger organisms were either hand-picked or isolated from the mass with a 0.5 mm. sieve, while the smaller ones, which passed through the meshes of the sieve were picked out with a small pipette. The specimens were then preserved in 5% formalin. Those with calcareous and chitinous skeletons were subsequently transferred to 70% alcohol.

ANALYSIS OF THE BOTTOM DEPOSIT

Grading of the Soil.—Each collection of bottom deposit was graded, by washing it through a series of sieves, following the method adopted by Allen (1899) and Borley (1923). A series of sieves with perforations 15 mm., 5 mm., 2.5 mm., 1.5 mm., 1 mm., and 0.5 mm., were used. The material passing through the 0.5 mm. sieve was collected into a small glass trough with some sea water. This was stirred vigorously, allowed to settle for one minute and decanted. By this process the fine sand which settles down to the bottom was separated from the semi-suspended

silt. Altogether, the eight grades of material thus obtained from each sample are designated as follows:—

1. *Stones* .. All inorganic material which will not pass through 15 mm. sieve.
2. *Coarse gravel* .. Material left on 5 mm. sieve.
3. *Medium gravel* .. Material left on 2.5 mm. sieve.
4. *Fine gravel* .. Material left on 1.5 mm. sieve.
5. *Coarse sand* .. Material left on 1.0 mm. sieve.
6. *Medium sand* .. Material left on 0.5 mm. sieve.
7. *Fine sand* .. Material which passes through 0.5 mm. sieve and which settles down in one minute after vigorous stirring with sea water.
8. *Silt* Material which passes through 0.5 mm. sieve and remains in suspension at the end of one minute.

For determining the texture of the deposit by sieving, the usual practice is to analyse a number of samples from each locality, in order to avoid possible errors. So, during the present investigation four samples were taken from each station and 500 c.c. of each sample was examined separately.

The different grades of gravel and sand were separated in the series of sieves, and the silt collected by passing the decanted turbid liquid through filter paper. All the samples were dried and weighed and the results expressed as percentages of the total weight (Ref. table). The analysis could not be said to be as accurate as that achieved by the use of the 'Levigating apparatus', particularly for very silty soils (Borley, 1923). However, it is 'sufficient to differentiate between soils which cannot easily be distinguished by inspection'—(Crawford, 1937b).

*Determination of Calcium Carbonate Content*¹.—For determining the calcium carbonate content of the samples, the shells and shell fragments in the first two grades were picked out by hand and weighed after drying, and the ordinary analytical method of estimation was followed in the case of the finer grades.

CONSTITUENTS OF THE BOTTOM DEPOSIT

The Calcium carbonate content of the bottom deposits from the stations under investigation is derived almost entirely from the remains of molluscs, echinoderms, serpulids, and foraminifera. The shell material from station IV is mostly formed of small shells of gastropods, while that of station VII and IX is composed mainly of shell fragments of lamellibranchs. At station I, unbroken shells of lamellibranchs predominate. The bulk of the shell-remains, collected from station VIII is formed of large *Operculina* tests and fragments of lamellibranch shells. Sponge spicules and small foraminiferan shells occur in the finer grades of almost all samples collected.

The percentage of silt in the samples collected from the different stations is not uniform (Ref. table). At stations I, II, VII, VIII, IX, X, XIII, and XIV, it is less than 11% of the total weight, whereas at the other stations it constitutes more than 79% of the total weight. The maximum percentage of 90.7 has been recorded from the Alleppey region, where it forms a soft semi-suspended superficial layer. The variations in the percentage of silt seem to follow a well-marked course and bear a definite relation to the position of the bar-mouth and the direction of currents. At Munambom, the deposit is formed of a large percentage of coarse

¹ I wish to express my thanks to Sri T. A. Ramakrishnan, Chief Chemist, Shark Liver Oil Factory, Trivandrum, for his kind assistance in the determination of CaCO₃ content of the various samples.

DESCRIPTION OF THE GROUNDS INVESTIGATED

Stations.	Brief description of stations.	Percentage composition of bottom deposit.										Percent- age of Calcium Carbonate.
		Stones.	Gravel.			Sand.			Silt.			
			Coarse. 4	Med. 5	Fine. 6	Coarse. 7	Med. 8	Fine. 9				
I 1	2 Munambom region, Barmouth, 2-3 furlongs offshore. Depth: 4-5 fathoms. About one furlong from the shore there is a shallow sand bank which forms the break-water; the bed of the sea beyond the break-water is formed of a more or less level ground with a thick deposit of brown gravel mixed with shells and shell fragments, mostly of lamellibranchs.	3 ..	4.3	1.4	6.0	18.0	51.4	18.7	0.2	10	11	12.3
II	Munambom region, south of Bar, 7-10 furlongs off the coast. Depth: 3-4 fathoms. Level ground, with a superficial deposit of fine grey sand and clay. Shells and shell fragments very rare. The coarse gravel is mixed up with fragments of decayed leaves and twigs. In grades 2, 4 and 5 small shells, bits of leaves and small pebbles are plentiful.	..	0.9	0.2	0.4	1.2	2.3	84.3	10.7			6.3
III	Due west of station II, about 14-16 furlongs offshore. Depth: 6-8 fathoms. Ground even, with a gradual slope seawards. The deposit is formed of fine black mud, rich in humus and fragments of decayed leaves	..	0.09	0.5	0.16	0.1	0.4	14.7	84.05			7.5
IV	Alleppey region, west of pier, 2-4 miles offshore. Depth: 6-7 fathoms. Ground even, formed of a semi-suspended soft, ooze-like mud. Small gastropod shells, shell fragments and polychaete tubes of agglutinated shell fragments are well represented.	..	0.1	0.8	2.1	1.9	4.0	10.2	80.9			15.5

DESCRIPTION OF THE GROUNDS INVESTIGATED—Contd.

Stations.	Brief description of stations.	Percentage composition of bottom deposit.									Percent- age of Calcium Carbonate.
		Stones.	Gravel.			Sand.			Silt.		
			Coarse. 4	Med. 5	Fine 6	Coarse. 7	Med. 8	Fine. 9			
I	2	3							10	11	
V	Alleppey, west of station IV, 12-15 miles off-shore. Depth: 12 fathoms. Ground even and flat, formed of soft ooze-like black mud mixed with small shells and shell fragments.	..	1-0	1-0	1-2	1-0	1-0	4-1	90-7	10-63	
VI	Ambalapuzha, 14-16 furlongs offshore. Depth: 5-7 fathoms. About 4-6 furlongs from the coast a mud bank runs parallel to the shore extending 10-15 miles southwards from Alleppey. Here a greater percentage of shells and shell fragment is noticeable.	..	2-0	1-7	1-3	2-1	3-5	10-5	79-5	19-6	
VII	Sankumughom region (Trivandrum) 4-6 furlongs offshore. Depth: 8-10 fathoms. Grades 2 and 3 consist mostly of shells and shell fragments, 4 and 5 of gravel, large foraminiferan shells and shell fragments.	..	3-5	1-0	6-0	11-0	30-5	46-0	2-0	15-2	
VIII	Trivandrum, west of station VII, 8-12 furlongs offshore. Depth: 12-15 fathoms. Ground even and flat and formed mostly of fine grey or black sand. Shells and shell fragments (mostly of gastropods) form the main constituent in grades 2, 3 and 4. The fraction in 1 mm. sieve is mostly <i>Operculina</i> shells. Shells of <i>Dentalium</i> and <i>Cadulus</i> are also common. In the higher grades remnants of cake-urchins and brittle stars are present.	..	0-1	0-1	0-3	1-0	1-7	88-1	8-7	13-02	

DESCRIPTION OF THE GROUNDS INVESTIGATED—*Contd.*

Stations.	Brief description of stations.	Percentage composition of bottom deposit.										Percent- age of Calcium Carbonate.
		Stones.	Gravel.			Sand.			Silt.			
			Coarse. 4	Med. 5	Fine. 6	Coarse. 7	Med. 8	Fine. 9				
I	2	3							10		11	
IX	Vizhinom Bay, 2-3 furlongs offshore. Depth: 6-8 fathoms. Shore rocky, ground hard and gravelly as at station I, but overgrown with green algae. Grades 2, 3 and 4 composed mostly of shells and shell fragments.	..	4.0	1.2	7.2	16.0	36.5	33.9	1.2		8.8	
X	Vizhinom region, due west of Bay, 8-10 furlongs offshore. Depth: 12.13 fathoms. Ground hard, but even and smooth. Composition of ground similar to that of station VIII, but here shells and shell fragments are scarce, and <i>Operculina</i> shells are very rare. Grades 2 and 3, mostly formed of shells, shell fragments, remnants of cake urchins, brittle stars, calcareous plates of <i>Balanus</i> and pteropod shells. Grades 4 and 5 formed of gravel and shell fragments; grades 6 and 7 formed of grey sand mixed, with minute shell fragments.	..	0.6	0.3	3.4	9.0	21.0	63.2	2.5		11.6	
XI	Kovilam (one mile west of Cape Comorin), 10-12 furlongs from shore. Depth: 12-14 fathoms. The littoral region between Cape Comorin and Kovilam is strewn with rocks and boulders, beyond this the ground is mostly sandy or silty with intermittent patches of rock.	..	..	..	0.3	0.9	2.5	7.7	88.6		19.9
XII	South-east of Cape Comorin, 16-18 furlongs offshore. Depth: 10-13 fathoms. Ground strewn with rocks and boulders down to the 12 fathom line and deposit formed of fine grey mud mixed with a large percentage of shells and shell fragments.	..	0.5	0.2	1.1	1.8	1.5	8.7	86.2		30.68	

DESCRIPTION OF THE GROUNDS INVESTIGATED—Concl'd.

Stations.	Brief description of stations	Percentage composition of bottom deposit.										Percent- age of Calcium Carbonate
		Stones.	Gravel.			Sand.			Silt.			
			Coarse. 4	Med. 5	Fine. 6	Coarse. 7	Med. 8	Fine. 9				
1	2	3	0.5	0.2	1.6	1.7	2.5	82.5	10	11		
XIII	Cape Comorin, east of Vivekananda rock, 12-14 furlongs from shore. Depth: 11-12 fathoms. Ground formed of fine grey sand, mixed with a large percentage of shells—mostly of gastropods—shell fragments, skeletal remains of echinoderms, lobsters, tubes of polychaetes and foraminiferan shells.	3.8	0.5	0.2	1.6	1.7	2.5	82.5	7.2	41.1		
XIV	North-east of Cape, due east of church, 12-18 furlongs offshore. Depth: 11-12 fathoms. Ground hard and sandy, strewn with pebbles and rocks mixed with fine shell fragments.	4.1	3.5	4.4	6.0	2.1	4.5	70.4	5.0	64.4		

gravel and sand, and the silt consists of remnants of decayed leaves and twigs. But, southwards near Alleppey the percentage of silt increases with its texture, becoming progressively finer. This type of fine silt mixed with sand forms an extensive deposit between Alleppey and Quilon, where it is known as the mud bank. In the vicinity of Quilon, the mud bank suddenly disappears, and between Quilon and Manakudi, the deposit is formed only of coarse sand mixed with a small percentage of silt. But, again in the region between Kovilam and S.E. of Cape Comorin the percentage of silt is almost that of the Alleppey region. These marked variations in the percentage of silt and in the occurrence of the mud bank in certain definite regions along the coast present an interesting phenomenon which calls for a more detailed investigation if a satisfactory explanation is to be offered.

BOTTOM FAUNA

Faunistic collections from the different stations are more or less representative of all the groups of bottom dwelling animals recorded in other countries from similar regions. An attempt has been made to identify most of the species collected, and all tentative identifications were confirmed by comparison with the named specimens in the Zoological Survey of India. A detailed study of the systematics and distribution of the crustaceans obtained has been made.¹

FORAMINIFERA

Foraminifera is one of the commonest groups, which is represented in all the samples collected, though varying in intensity in different places. They are rare in the regions where the deposit is formed of fine silt, while they are abundant in the sandy regions (stations VIII and X).

Family Astrorhizidae

Astrorhiza granulosa Brady.

Rarely obtained from station VIII.

Family Saccamminidae

Protonina testacea Flint.

Rare at station VIII.

Family Textulariidae

Textularia albatrossi Cushman.

Common at stations XI and XII.

Family Miliolidae

Massilina australis Cushman.

Rare at station XIII.

Spiroloculina grateloupi d'Orbigny.

Common at stations VIII and XIV.

Spiroloculina exima Cushman.

Common at station XIII.

Spiroloculina affixa Terquem.

Common at stations VIII, XII, XIII and XIV.

¹ *Bull. Cent. Res. Inst.*, Vol. III, Sec. C. (Under publication.)

Spiroloculina excavata d'Orbigny.

Common at station VIII.

Miliola valvularis Flint.

Common at station VIII.

Family Ophthalmidiidae

Sub-family CORNUSPIRININAE

Cornuspira involvens (Reuss).

Rare at station XII.

Family Lagenidae

Sub-family NODOSARIINAE

Robulus cultratus Montfort.

Common at stations VIII and X.

Family Nonionidae

Nonion grateloupe (d'Orbigny).

Rare at station XIV.

Elphidium simplex Cushman.

Common at station XIII.

Family Camerinidae

Sub-family CAMERININAE

Operculinella cumingii (Carpenter).

Rare at station VIII.

Operculina granulosa (Leymerie).

Three forms of this species¹ were obtained abundantly from stations VII, VIII, IX, and X.

Family Buliminidae

Entosolenia squamosa Carpenter.

Common at station X.

Entosolenia marginata Carpenter.

Abundant at stations VIII, IX and X.

Family Peneroplidae

Sub-family SPIROLININAE

Peneroplis lanatus (Fichtel and Moll).

Rare at station VIII.

Spirolina arietina (Batseh).

Common at station XIII.

Monolysidium politum Chapman.

Rare at station XIII.

¹ Kurian (1951), *Current Science*, XX, p. 335.

Family Rotalidae

Sub-family ROTALIINAE

Eponides repanda (Fichtel and Moll).

Common at stations VIII and XIII.

Rotalia calcar (d'Orbigny).

Common at station VIII.

COELENTERATA

Coelenterates are very poorly represented in the bottom fauna. As the region under investigation is formed mostly of soft mud or sand, hydroids are seldom found. In station VIII, however, colonies of *Clytia* sp. were obtained on two occasions attached to gastropod shells and a small piece of rope.

Among the pelagic forms of medusae only one species, *Olindias singularis* Brown, occurs at depths; usually it appears in swarms in February and March when they are well represented in dredge and beam trawl collections from the Trivandrum region in 10-15 fathoms.

ECHINODERMATA

Large star fishes and sea urchins are found in the rocky regions of the coast, especially between Cape Comorin and Colachel, but they are not included in the present work since they are seldom obtained in the dredge or beam trawl at the stations investigated. Only small species of cake urchins, brittle stars and star fishes which are generally found in bottom collections are included here.

Asteroidea

Astropecten indicus Doderlein.

The largest specimen measures 14 mm. across the disc.

Rarely obtained from stations VIII and X; in a deposit of fine grey sand mixed with a small percentage of shell fragments and silt.

Ophiuroidea

Ophiocnemis sp.

Small specimens measuring 2-4 mm. across the disc. were obtained sparingly from stations V, VIII, X and XIV.

Clypeastridea

Laganum decagonale de Blainville.

Specimens of this species collected from this coast are covered with spines all over the body and in this respect they resemble the specimens in Crichton's collections preserved in the Madras Government Museum.

Occurs commonly at station XI, where the deposit is mostly silt, only rarely obtained from stations VIII and XIV in a fine sandy bottom.

Echinodiscus auritus (Leske).

Common at stations VIII, XIII and XIV in a deposit of fine silty sand.

MOLLUSCA

Molluscan shells, complete as well as fragments, form a very important constituent of the bottom deposits of this coast. A large proportion of this is formed of lamellibranch shells though in certain regions gastropod shells predominate. These shells are mixed up with the mud or sand in certain places such as Munambom, Kayamkulam, Quilon, and the region between Cape Comorin and Colachel. They are washed ashore in considerable quantities and are popularly called 'drift shells'. The total quantity of drift shells collected annually is approximately 2,000 tons.

In the present report only a part of the collection is included as identification of all the forms obtained was found difficult.

GASTROPODA

Family Trochidae

Trochus radiatus Gmelin.

Two specimens 18 and 19 mm. in height were obtained from station XIV.

Family Naticidae

Natica lineata Lamk.

A single specimen from station VIII from a sea bottom formed of fine sand mixed with a small percentage of silt and shell fragments. This species is usually found on sandy or gravelly bottom from low water to 90 fathoms.

Albula mamilla Lamk.

A single dead shell from station VIII in dredge.

Family Bursidae

Bursa margaritula (Deshayes).

Specimens up to 25 mm. in height were found common at stations VII and VIII in a deposit of gravelly sand or fine silty sand.

Family Ficidae

Ficus ficus (Lin.).

A single live specimen, 45 mm. high from station VIII.

Family Muricidae

Thais bufo. (Lamk).

Only two specimens were obtained from station XIV.

Thais margariticola (Broderip).

Live specimens up to 23 mm. high were collected in large numbers from stations VII and VIII. The specimens collected from 15 fathoms in fine sand are greyish, while those from a bed of sand and gravel at a depth of 10 fathoms are brown.

Family Buccinidae

Bebaylonia spirata (Lin.).

A single specimen, 32 mm. high from station VII, in dredge collection.

Babylonia zeylanica (Lamk.).

Two specimens 42 mm. and 62 mm. high respectively were obtained from station VIII.

Family Olividae

Oliva hiatula (Gmlin).

Specimens up to 30 mm. in height were common at stations VII and VIII. Empty shells inhabited by hermit crabs were also occasionally found.

Oliva volvarioides Duclou.

A common species at Cape Comorin, obtained from station XIV.

Family Turbinellidae

Xancus pyrum (Lin.).

This species is represented by the varieties *acuta* and *obtusa* obtained at station VIII in dredge and beam trawl.

Family Harpidae

Harpa conoidalis Lamk.

One live specimen and a dead shell inhabited by a hermit crab were obtained at station VII in a deposit of sand and gravel. The shell is 62 mm. high, deep brown, and has 13 distinct equidistant ribs outside; aperture large, notched in front. The animal has a very large crescent-shaped foot with five deep lateral fissures at almost regular intervals. Crichton (1941) observes that when the animal is disturbed or irritated the foot breaks off at these fissures. But the specimen collected at Trivandrum did not show this behaviour though it was kept alive in the aquarium for nearly two months.

Family Turridae

Turris indica Roding.

Specimens up to 35 mm. in height were common at stations IV, V and VIII. The colour of the shell is usually brown or grey with white markings.

Family Conidae

Conus betulinus Lin.

In this massive-shelled species the periostracum is thick and decorated with rows of dark brown spots. A single specimen 55 mm. in height was obtained at station VIII.

Family Terebridae

Terebra columnaris Kiln.

This is a common species in the mud bank region of the Alleppey Coast, where it is more abundant in the deeper waters; obtained from stations IV, V and VI.

PTEROPODA

Sub-order THECOSOMATA

Family Cavoliniidae

Creseis acicula Rang.

A very common form along the Travancore Coast, especially at stations III, VII, VIII, X and XIV. It has also been observed in swarms in the plankton from December to April.

SCAPHOPODA

Family Dentaliidae

Dentalium cancellatum Sowerby.

A single specimen 50 mm. long from station V.

Dentalium paucicostatum Boissevain.

Only one specimen 11.9 mm. long from station VIII.

Dentalium quadrangulatum (Hanley) Sowerby.

A single specimen 15.6 mm. long was collected from station VIII, and numerous specimens from station XIV.

Family Siphonodentalidae

Cadulus longilobatus Boissevain.

Numerous specimens up to 9.2 mm. in length were obtained from stations VII and VIII. They are more abundant at 15 fathoms, during February and March.

PELECYPODA

Family Mytilidae

Modiolus plumescens Dunker.

Empty shells of this species were obtained from stations VIII, X and XIV.

The specimens collected closely agree with the named Samoan collection in the Zoological Survey of India. An allied species, *M. metcalfei* (Hanley), has been recorded from the Madras Coast and the Chilka lake, but the differences between the two are well marked.

CEPHALOPODA

Family Sepiolidae

Sepioida sp.

Collected at station VIII. Specific identification was difficult, in view of the fact that all the four specimens obtained were immature, the largest of them being only 14.5 mm. long and 9.5 mm. broad.

CRUSTACEA

Family Calappidae

Sub-family CALAPPINAE

Calappa lophos (Herbst).

Collected at stations VIII and X from fine grey sand near the 15-fathom line; young ones are abundant during January to April.

Matuta lunaris (Forsk.).

This is common at stations VII and VIII on gravelly sand and on fine sand.

Dorippe dorsipes (Linn.) Miers.

Obtained at stations VIII and XI, not very common.

Family **Portunidae**Sub-family **PORTUNINAE***Neptunus sanguinolentus* (Herbst).

Common at most of the stations. Ovigerous females were collected in large numbers at stations IX and X from August to October. During this season they were abundant at Vizhingom at 10 fathoms on sandy ground overgrown with sea weeds. Post-larval forms of this species were also obtained in dredge collections at 15 fathoms from station VIII during January to April.

Neptunus (Amphitrite) gladiator (Fabr.).

Both adults and young ones were common in stations VII, VIII, IX and X. The maximum abundance was noticed at station X where the ground is formed of fine grey sand with a small percentage of silt and shell fragments.

Neptunus (Amphitrite) argentatus (White).

Obtained in dredge collections at station VIII during February and March.

CARIDEAFamily **Hippolytidae***Latreutes mucronatus* (Stimpson).

Represented only by a single ovigerous female specimen, 12.3 mm. long obtained from station VIII.

Tozeuma armatum Paulson.

A single specimen 37 mm. long from station VIII. It was found among brown algae from which it is hardly distinguishable, owing to its colour which harmonises very well with that of the algae.

Hippolysmata ensirostris Kemp.

A single specimen measuring 36 mm. in length was obtained from station VIII.

Family **Palaemonidae**Sub-family **PONTONINAE***Urocaridella gracilis* Borradaile.

Two specimens, of which the large ovigerous female is 31 mm. long, were obtained from station VIII.

Periclimenes (periclimenes) obscurus Kemp.

Numerous specimens up to 13 mm. in length obtained from station VIII, appeared in swarms in March, 1945.

Periclimenes (Ancyllocaris) elegans (Paulson).

Four specimens of this species of which the largest ovigerous female is 14 mm. long were collected in dredge from station VIII during March, 1945.

Family Crangonidae

Pontophilus hendersoni Kemp.

Five ovigerous females and two immature specimens¹ were obtained from station VIII in dredge and beam trawl collections.

Pontophilus parvirostris Kemp.

A single non-ovigerous female 8.5 mm. long was obtained from station VIII.

PENAEIDEA

Family Penaeidae

Sub-family PENAEINAE

Metapenaeus affinis (Milne Edwards).

M. affinis is commonly found in the coastal waters from May to October in all localities where the bed of the sea is sandy. It is comparatively rare in the muddy regions between Munambom and Quilon.

Metapenaeus dobsoni (Miers).

M. dobsoni is common in the mud bank regions between Alleppey and Quilon, with maximum abundance from December to April. The specimens collected from stations IV, V and VI are 3"-5" long.

Metapenaeopsis mogiensis Burkenroad.

Specimens of *M. mogiensis* up to 2.5" in length were collected from stations VII and VIII. Immature ones appear in swarms during January and the adults in March.

Parapenaeopsis stylifera (M. Edwards).

P. stylifera commonly occurs in the coastal waters from May to October. During this season, specimens 3"-4.8" long were collected in large numbers in dredge and beam trawl from stations IV, V, VII and IX. It is only sparingly found from January to April. Young ones 0.5"-0.75" long appear in swarms during August.

Parapenaeopsis stylifera var. *coromandelica* Alcock.

A single specimen 3.3" long was collected from station VII in August, 1946.

Parapenaeopsis maxillipedo Alcock.

Specimens up to 3.6" in length were collected in large numbers at station VIII from January to April. It is rare at stations VII and IX.

Sub-family EUSICYONINAE

Eusicyonia fallax (de Man).

One adult female 30.0 mm. long was obtained from station VIII.

Eusicyonia lancifer (Olivier).

One female specimen 30 mm. long and two male specimens 40 and 18 mm. long respectively were obtained from station VIII in February and March, 1945.

¹ Kurian (1952), *Current Science*, XXI, p. 316.

Family Sergestidae

Sub-family SERGESTINAE

Acetes erythraeus Nobili.

A. erythraeus is present on almost all types of grounds within the 15-fathom line. In the Trivandrum-Vizhingom region it is found throughout the year and appears in swarms from January to April.

Sub-family LUCIFERINAE

Lucifer hanseni Nobili.

L. hanseni is common on this coast and is obtained abundantly both in plankton and bottom collections from almost all stations. It appears in swarms from August to October and March to May on the Trivandrum Coast. It is more abundant in the bottom of deeper regions.

Lucifer reynaudi (Milne Edwards) Dana.

L. reynaudi is rare in the plankton, but good numbers of it were collected from August to October from bottom collections at station X.

EUPHAUSIACEA

Nyctiphanes simplex Hansen.

In March, 1946, larval and post-larval forms of this species up to 9.9 mm. in length appeared in swarms at station VIII.

MYSIDACEA

Family Mysidae

Sub-family RHOPALOPHTHALMINAE

Rhopalophthalmus egregius Hansen.

Common in most of the stations from shore to 15 fathoms, and with swarms in stations VII and IX between November to January.

Sub-family GASTROSACCINAE

Gastrosaccus dunckeri Zimmer.

This is common at stations VII and VIII and appears in swarms in January. Unlike the previous species (*R. egregius*), it is more numerous in deeper waters and in deposits formed of fine sand and silt. Egg-bearing females were obtained in March.

Gastrosaccus muticus Tattersall.

Specimens up to 6.1 mm. in length were occasionally obtained from station X in September and October.

Gastrosaccus Kempi Tattersall.

A single male 9.8 mm. long was obtained from station VIII.

Fromysis macropsis Tattersall.

This is common in stations VII-X. Males 8.5 mm. long and egg-bearing females 8 mm. long were obtained in small numbers during all months. Swarms were observed in stations IX and X between August and January and in stations VII and VIII between December and February.

TRIBE MYSINI

Neomysis indica Tattersall. •

Large numbers of this species were obtained from stations IX and X from August to December with swarms of ovigerous females in August and September. It is rarely found in March in station VIII, frequenting deep water stations more than shallow ones.

STOMATOPODA

Family Squillidae

Squilla hieroglyphica Kemp.

Two male specimens 61 mm. to 62 mm. long were obtained from station VII.

Squilla nepa Latreille.

This is common in the Alleppey-Munambom region where the bed of the sea is formed of fine silt. Specimens up to 92 mm. in length have been collected from stations IV-VIII and XI, the maximum intensity of occurrence being in stations IV-VI from December to March.

Squilla holoschista Kemp.

Larval and post-larval specimens up to 35 mm. in length were obtained in both dredge and plankton nets throughout the year. Swarms were observed in February and March at stations VII-X.

Squilla wood-masoni Kemp.

Specimens with a maximum length of 100 mm. are well represented in the collections from stations VII, VIII and IX during March and April. Larval and post-larval forms were observed in large numbers during February and March.

Lysiosquilla maculata (Fabricius).

Represented by a single male 295 mm. long collected in beam trawl from station VIII.

CUMACEA¹

Twenty-two species of this group were collected in the course of the present investigation. These small crustaceans have preference for a bed of fine sand mixed with a small percentage of silt and calcareous fragments, a condition typical of the Trivandrum-Vizhingom region in the 15-fathom line. Like other crustaceans they occur in abundance from December to March.

ISOPODA

Sub-order FLABELLIFERA (Cymothoidea)

Family Anthuridae

Apanthura sandalensis Stebbing.

A common species at station XIV, but rare at station VIII.

Nerocila orbignyi (Guerin).

Represented by a single immature specimen 12.1 mm. long, obtained from station VIII.

Nerocila sundaica Bleeker.

Represented in the present collection by a single specimen 26 mm. long obtained from station VII.

¹ Vide Kurian (1951), *Bull. Cent. Res. Inst.*, II(c), pp. 77-118.

Sub-order IDOTEOIDEA

Family Idoteidae

Synidotea variegata Collinge.

A common form at stations IX and X, being more numerous among sea-weeds near the shore.

Family Munnidae

Munna acarina Miller.

0.79 to 1.05 mm. in length, they occur throughout the year at station VIII, with swarms in March and April.

PYCNOGONIDA (Pantopoda)

Family Ammotheidae

Nymphopsis acinacispinatus Williams.

This species is represented by a single immature specimen obtained from station IX; but it seems to be the first record of the genus from India.

Parapallene kemp Calman.

Common at station IX among sea-weeds.

Family Phoxichilidiidae

Anoplodactylus cribellatus Calman.

Represented in the present collection by two male specimens from station IX.

Anoplodactylus sexatilis Calman.

Two female (?) specimens of this species were obtained from station IX along with other pyenogonids.

CEPHALOCHORDATA

Branchiostomidae

Branchiostoma lanceolatum (Pallas).

Plenty at stations VIII, X and XIV; appeared in swarms during September to December.

PISCES

In the following account only fishes obtained in the dredge and beam trawl within the 15-fathom limit are dealt with. These include 36 species, of which 16 are flat fishes (Heterosomata).

Super-order TELEOSTEI

Order INIOMI

Family Synodontidae

Trachinocephalus myops (Bl. sch.).

Five specimens 2.1" to 7" in length were obtained from stations VII and VIII during February and March.

Saurida tumbil Bloch.

S. tumbil is a common species along the Trivandrum-Vizhingom region. Specimens up to 7" in length have been obtained in the beam trawl in stations VII,

VIII and IX from December to March. They are found more near the shore in March, and are commonly obtained in the 'shore seines' during the season.

Order HETEROSOMATA

Family Psettodidae

Psettodes erumei (Schneider).

Specimens 13" to 15" in length have been obtained in the beam trawl from the Trivandrum Coast at a depth of 10 to 12 fathoms from January to March.

Family Bothidae

Sub-family PARALICHTHINAE

Pseudorhombus triocellatus (Schneider).

Specimens up to 5.5" in length have been obtained from stations VII to XI. Between January and April, it is common near the shore, and is only rarely observed beyond the 12 fathom limit.

Pseudorhombus malayanus Bleeker.

Only three specimens, 7.7"-8.5" in length obtained in May, 1947 from station VIII are represented in the collection.

Pseudorhombus arsius (Hamilton).

P. arsius has been obtained in very small numbers from stations VII to XI.

Sub-family BOTHINAE

Engyprosopon grandisquama (Tem. and Scheleg.).

Specimens 0.8"-4.1" in length, were observed in most of the collections from the Trivandrum-Vizhingom region. The species is found in much larger numbers near the shore than in deep water.

Bothus bleekeri Steindachner.

Only two males, 4.6" and 5.2" in length, have been obtained from station VIII.

Bothus ovalis (Regan).

Sparingly obtained from the Trivandrum-Vizhingom region at stations VII to X. The post-larval forms of this species have also been obtained from station VIII.

Family Soleidae

Brachirus commersoni (Lacep.).

This is represented only by a single specimen 2.5" in length obtained from station IX.

Brachirus albomaculatus (Kemp).

Specimens up to 7.8" in length have been obtained in small numbers from stations VII to X from December to March. Those obtained from the shallow regions are brownish with deep brown spots, whereas those caught from the deeper regions are grey with black spots.

Zebrias altipinnis (Alcock).

A solitary specimen 5.8" long was obtained from station VIII.

Family Cynoglossidae

Paraplagusia bilineata (Bloch).

This is common along the Trivandrum and Vizhingom coasts, numerous specimens up to 7" in length having been collected from stations VII to X. The post-larval forms are usually found in the deeper regions.

Cynoglossus versicolor Alcock.

From December to March this species has been obtained in small numbers from stations VII, VIII and IX. Post-larval forms were also sparingly obtained from station VIII.

Cynoglossus dubius Day.

Numerous specimens up to 1.8" in length were collected from stations IX and X with swarms appearing in August and October.

Cynoglossus monopus (Bleeker).

This is common in the mud-bank region in stations IV, V and VI, from December to April along with *Metapenaeus dobsoni*. The specimens are 3" to 4.5" in length.

Cynoglossus puncticeps (Richardson).

Specimens up to 6.6" in length have been collected in small numbers from August to October in station X.

Cynoglossus lida (Bleeker).

C. lida has only been obtained in small numbers from stations VII and VIII from October to December. The largest specimen collected is 7.2" in length.

Super-order ACANTHOPTERYGII

Order PERCOMORPHI

Family Ambassidae

Ambassis interrupta Bleeker.

Common in the shallow muddy regions of Ambalapuzha and Alleppey in March and April. The specimens collected from station VI are 2.5" in length.

Family Apogonidae

Apogon thurstoni Day.

A common species at stations VII, VIII, IX and X. Specimens up to 2.6" in length were collected in the dredge and the beam trawl from December to April; observed to be more common in deep water than in the shallows near the shore. The colour of the specimens also varies in accordance with the nature of the substratum.

Family Mullidae

Upeneus vittatus (Forsk.).

A common bottom feeding fish at stations VII to X and XIV, generally caught in the shore seine-nets from March to May and September to November, from the Trivandrum Coast.

Upeneus indicus (Shaw).

A common species at stations VII to X. Like *U. vittatus*, this is found more in deep water than near the shore. The largest specimen obtained is 4.7" in length.

Family Polynemidae

Polynemus heptadactylus (Cuv. and Val.).

A number of advanced post-larval forms, 0.6"-0.8" in length were obtained from stations VII and VIII during January to March, and swarms appeared in March, 1946, along the Trivandrum Coast near the 15 fathom line. Adult specimens of this species were subsequently observed at station XIV.

Family Sillaginidae

Sillago sihama (Forsk.).

Specimens up to 8" in length were commonly obtained at stations VII and IX from August to December. This species is seen to haunt the shore-waters when the mysids appear in swarms. Advanced post-larval forms up to 1" in length were also obtained from station VII in March.

Family Cottidae

Suggrundus tuberculatus (Cuv. and Val.).

Large numbers of specimens up to 4.4" in length were collected from stations VII to X. The species is abundant near the 15-fathom line during March and April.

Order CATAPHRACTI

Family Scorpaenidae

Scorpaenopsis rosea Day.

Specimens 1.1" to 1.5" in length were commonly obtained from stations VII and VIII among sea-weeds.

Pterois macrura Alcock.

A single specimen 2.5" long was obtained from station VIII among sea-weeds.

Pterois russellii (Van Hass).

A common species at stations VII and VIII; appeared in swarms in April and May, 1946. Most of the specimens collected in the first week of May, 1946, from the Trivandrum Coast bore indications of the detrimental effects of an external parasite (*Caligus pterois*).¹

Gymnapistus dracaena (Cuv. and Val.).

Nine specimens, 1.5" to 2.5" in length, were obtained from station VIII along with other Scorpaenoids.

Order PHARYNGOGNATHI

Family Labridae

Novacula punctulata Cuv. and Val.

A common species along the Trivandrum Coast at stations VII and VIII from February to April.

¹ Kurian (1951), *Bull. Cent. Res. Inst.* I, pp. 1-21.

Order GOBIOIDEA

Family Trypauchenidae

Trypauchen vagina (Bl.).

A common fish found in the muddy regions of stations III, V, VI and XII. Numerous specimens, 1-2" to 6" long, were collected. It has been observed in the backwaters also.

Order JUGULARES

Family Paraperidae

Paraperis pulchella (Temm. Schleg.).

Represented in the collection only by a single specimen 2-9" long obtained from station VIII.

Family Callionymidae

Callionymus longicaudatus (Temm. and Schleg.).

Numerous specimens measuring up to 5-7" in length were collected from stations VII, VIII and IX. In March they were observed in large numbers near the 15-fathom line along the Trivandrum Coast.

Family Trichonotidae

Trichonotus setigerus Ble. and Schn.

Only two specimens, 2-2" and 1-8" in length, were obtained from station VIII.

Order PLECTOGNATHI

Family Triacanthidae

Triacanthus brevirostris Temm. and Schleg.

Two specimens 0-9" long were obtained from station IX.

Family Monacanthidae

Pseudomonacanthus tomentosus Linn.

Six specimens, 1" to 2-1" long were collected from station VIII.

GENERAL OBSERVATIONS

From the foregoing account it will be seen that the stations investigated are representative of all types of grounds, viz., rocky, sandy and muddy—found along the Travancore Coast. The fauna in each region is also found to vary with the nature of the deposit.

The predominant groups of animals represented in the collection are Foraminifera, Mollusca and Crustacea. Foraminifera are abundant near the 15 fathom line in fine silty sand. Towards the shore, where the ground is formed of a mixture of gravel and sand, and in clay they are relatively rare. The only species which is common in the shore regions is *Operculina granulosa*, but even this is more abundant near the 15-fathom line at station VIII, where it constitutes 1-2% of the total dry weight of the deposit in March collections.

Though hydroids are plentiful on the submerged rocks and boulders at Cape Comorin, Vizhingom and other regions, they are not included in the present work, as they are seldom obtained in dredge and beam trawl collections. On sandy

ground hydroids are rare, only isolated specimens sometimes being found attached to foreign objects. Thus for example a few small colonies of *Clytia* sp. attached to gastropod shells and a small piece of rope were obtained on two occasions. The only species of medusa obtained in the bottom collections is *Olindias singularis*, which occurs in swarms near the 15-fathom line at station X in February and March.

The Echinoderms are comparatively rare in the collections, though no doubt a large number of species is found on the submerged rocks and weed beds. However, four species have been collected from Trivandrum at a depth of 12–15 fathoms, where they are found in large numbers during February and March.

Molluscs occur both in the inshore regions and near the 15 fathom line. *Trochus radiatus*, *Natica lineata*, *Albula mamilla*, *Ficus ficus*, *Thais bufo*, *Babylonia zeylanica*, *Oliva volvaroides*, *Xancus pyrum*, *Turris indica*, *Conus betulinus*, and *Modiolus plumescens* have been obtained only from the deeper regions, whereas *Babylonia spirata* and *Harpa conoidalis* are found only at station VII near the shore. *Bursa margaritula*, *Thais margariticola*, and *Oliva hiatula* are found both in the inshore regions and near the 15-fathom line, though they are more abundant in the latter region. Specimens of *Thais margariticola* collected from the inshore regions are brown, while those obtained from 15 fathoms are greyish. *Creseis acicula* and *Cadulus longilobatus* are found nearer the 15-fathom line than the shore and in swarms at Trivandrum from February to April.

Crabs are abundant at 15 fathoms, though occasionally they are found in the inshore regions also. Post-larval forms of a number of species including those of *Neptunus* spp. were obtained in dredge collections from station X, from January to April.

All the species of Caridea recorded in this paper were collected from January to April at depths near about 15 fathoms, most of them represented only by single specimens. *Periclimenes obscurus* was observed in swarms in March, while *Pontophilus hendersoni* was noticed in small numbers in fine sand and silt.

Of the Penaeid prawns, *Metapenaeopsis mogiensis* and *Parapenaeopsis maxillipedo* are found in the inshore regions, though they are more abundant near the 15-fathom line. *Parapenaeopsis stylifera*, on the other hand, occurs abundantly in the coastal waters in a bed of gravelly sand from May to October, and rather sparsely from January to April. Young ones of this species, 0.5"–0.75" in length appears in swarms during August. *Metapenaeus dobsoni* occurs in abundance in the mud banks from December to April providing the chief fishery in that region during the season. The two species of *Eusicyonia* occur in 15 fathoms at Trivandrum in February and March.

The sergestids are common on almost all types of grounds, varying from gravelly sand to fine silt. In the Trivandrum region it is prevalent throughout the year and appears in swarms from January to April. *Lucifer hansenii* is pelagic as well as demersal from March to May. Where demersal they are usually collected from the deeper regions.

Menon (1945) observed Mysids to form an important constituent of the macroplankton elements and to be common along the Trivandrum Coast except in August and September, with a period of maximum intensity from February to April. The present investigation, however, shows that each species has a separate maximum intensity. Thus for example *Rhopalophthalmus egregius* reaches its maximum abundance from November to January, *Gastrosaccus dunckeri* in January, *Afromysis macropsis* from December to February, and *Neomysis indica* from August to September. It may also be noted that they are essentially demersal organisms occurring more abundantly in the bottom deposits than in the plankton. *R. egregius* is found more towards the shore, while *G. dunckeri* and *A. macropsis* are observed in larger numbers at 15 fathoms.

Squilla is very commonly obtained in prawn nets along with *Metapenaeus dobsoni*, in the mud bank regions of Ambalapuzha and Alleppey. A few forms

were also collected at Trivandrum near the 15-fathom line from December to March. Larval and post-larval forms were observed in dredge and plankton nets throughout the year, with a period of maximum intensity in February and March.

Like other Crustaceans, the Cumacea are also found in large numbers near the 15-fathom line, in a deposit of fine sand mixed with silt and shell fragments. The period of their abundance is also from December to March.

Of the five species of Isopoda collected from this region only *Nerocila sundaica* was obtained from station I in a bottom of gravelly sand. All the other species were collected from 15 fathoms. *Munna acarina* is common throughout the year in the Trivandrum region and swarms were noticed during March and April.

Thirty-six species of fishes have been collected. Of these, *Apogon thurstoni*, *Polynemus heptadactylus*, *Suggrundus tuberculatus*, *Scorpaenopsis rosea*, *Pterois russellii*, *Novacula punctulata* and *Callionymus longicaudatus* are found near the 15-fathom line, while *Saurida tumbil*, *Upeneus vittatus*, *Upeneus indicus*, and *Sillago sihama* are common in the shallower regions. All these species have their maximum abundance at Trivandrum from December to March.

Altogether 16 species of flat fishes (Heterosomata) have been collected. Of these, only four species, namely *Pseudorhombus triocellatus*, *Engyprosopon grandisquama*, *Paraplagusia bilineata*, *Cynoglossus dubius* and *C. monopus* are common, while all the others are rare or only casual visitors from the deeper regions during certain seasons. *Psettodes erumei*, *Pseudorhombus triocellatus*, *Engyprosopon grandisquama* and *Paraplagusia bilineata* are generally found in shallow regions in less than 10 fathoms in a gravelly sand bottom, while *Pseudorhombus arsius*, *Bothus ovalis*, *Brachirus albomaculatus* and *Cynoglossus versicolor* usually occur beyond 12 fathoms in a fine sandy bottom, and have a maximum abundance from December to March. *Cynoglossus monopus* is commonly caught in the mud bank regions along with prawns, and occurs in large numbers from December to April.

Analysis of the stomach contents of the bottom feeding fishes shows that their food consists mostly of Crustaceans including Sergestids, Mysids and Cumaceans. During the season when Crustaceans are abundant, these fishes are also found in large numbers. Mysids constitute an important constituent of the food of the flat fishes, *Platycephalids*, *Sillago sihama*, and *Saurida tumbil*.

Association of animals in relation to texture of ground

Borley (1923) observes that the character of marine deposits is an important factor in the determination of the distribution and abundance of the species living in or upon the sea-bed or in its vicinity. It has also been found that each species has a preference for a particular soil or range of soils and the cause of the soil association of the bottom living animals is to be found in the modifications of each group of animals in respect of its method of feeding.

According to the nature of the composition, the bottom deposits collected from the different regions may be classified as 'Mud', 'Sand and Gravel' and 'Fine Sand and Silt'. The first type is represented at stations III, IV, V, VI, XI and XII, the second at stations I, VII and IX and the third at stations II, VIII, X, XIII and XIV. The characteristics of the bottom deposit seems to influence the population density of the bottom fauna at the different stations. Certain species have a restricted occurrence in a particular type of deposit, whereas others have a wide distribution at different regions, though their intensity of occurrence is different.

In the muddy deposits, penaeid prawns, Stomatopods, Gastropods, Pleuronectids and Gobioids are found in fairly good numbers. But, even here the organic content of the silt has an important rôle and the silt containing humus as occurring at the Alleppey 'mud bank' region affords greater possibilities for the mud fauna, and prawns, stomatopods and flat fishes are invariably found in all the collections from this region. At stations XI and XII, though the percentage of silt in the

samples collected is almost the same as at the mud bank region, prawns, stomatopods and flat fishes are rather rare, presumably owing to the scarcity of organic remains in the deposit.

The 'gravel and sand' deposits occur towards the shore, and in considering the distribution of fauna in this region the influence of the shore has also to be taken into account. Lamellibranchs, Crabs, *Acetes*, Mysids, Isopods, and fishes like *Sillago sihama*, *Apogon thurstoni*, *Saurida tumbil*, *Callionymus longicaudatus* are well represented in this region, while penaeid prawns, Cumaceans, Caridea, *Lucifer*, Stomatopods, Cephalochordates, and Pleuronectids are only rarely observed. At Trivandrum *Rhopalophthalmus egregius* is found in abundance in this region from November to January and during this season *Therapon spp.* and *Sillago sihama* are found in association with this species of mysis which form the food of these fishes.

The number of species and the actual population of all individuals of all the species combined is greatest in the third region where Foraminiferans, Annelids, Echinoderms, Gastropods, Pteropods, Scaphopods, Crabs, Cumacea, Caridea, *Lucifer*, *Acetes*, Mysis, Isopods, Cephalochordates, Pleuronectids, Scorpaenoids and Platycephalids are generally found, though their intensity varies according to the seasons.

SUMMARY

This is a preliminary study of the Bottom Fauna and Bottom Deposits of the Travancore Coast based on samples taken with a dredge and beam trawl from 14 different stations distributed along the Coast within the 15-fathom line.

The grade composition, the organic constituents and the calcium carbonate content of the bottom deposits from the different stations have been determined.

The foregoing attempt to correlate the occurrence of various species with different types of soil has resulted in indicating a definite relationship between the bottom animals and the texture of the soil in which they are found.

'Fine sand' with mud and calcareous deposit seems to be the best ground for macro-fauna consisting mostly of Crustaceans, the dominant group represented in the region under investigation.

Examination of the stomach contents of the bottom feeding fishes shows that most of them feed voraciously on Mysids, Cumaceans, Sergestids, and other bottom dwelling Crustaceans and Polychaetes.

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STUDIES ON THE FOOD, FEEDING HABITS AND ALIMENTARY TRACT OF THE GREY MULLET, *MUGIL TADE* FORSKÅL

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I. INTRODUCTION

The importance of studies on the food of fishes in fishery biological investigations is well known, and considerable attention is being paid at the moment to this problem in India. Several publications on the subject have appeared recently, but unfortunately a large majority of these are based on examinations of small numbers of specimens collected at random. To obtain a correct picture of the nutrition and feeding adaptations of a fish, a comprehensive study of all available age groups, covering all the seasons and environments of its occurrence, is essential. The seasonal variations in the nature of the food of fishes can be interpreted properly only if we have a knowledge of the availability of the constituents of their dietary in the habitats. The value of such an ecological investigation to elucidate the food chains that exist in our waters and to explain the behaviour of animals cannot be overstressed (Elton, 1927 and Hora, 1944). Among the few detailed investigations on the food of fishes conducted in India, the more important ones are those of Hornell and Naidu (1923), Job (1940, 1941*a* and 1941*b*), Menon (1942), Mookerjee *et al.* (1946*b* and 1949) and Bapat and Bal (1950).

For a correct understanding of the feeding habits of a fish, a study of the anatomy of the organs of feeding and digestion is necessary. 'An examination of the special relations of food and feeding structures gives clues, not only to the present significance of fishes but also their past effect on life at large, showing how they must have modified the course of evolution' (Forbes, 1888). The feeding apparatus exhibits one of the most significant examples of correlation, and the investigation of the food of a fish will be incomplete without a study of its alimentation. Al-Hussaini (1945) has given an excellent review of the previous work relating to the correlation of the structure of alimentary tracts with the feeding habits of fishes. His contributions (Al-Hussaini, 1945, 1946 and 1949) and that of Angelescu and Gneri (1949) have served to elucidate some of the most interesting morphological adaptations among fishes. Practically no work on these lines has been done in any detail in India. Rahimullah (1935, 1939 and 1943), Dharmarajan (1936), Vanajakshi (1938), Sarbahi (1940) and Mohsin (1944-46) have all dealt with the structure of the alimentary tract of fishes or of their appendages; but have not made simultaneously a detailed study of the food of these fishes or correlated the nature of the food and the feeding habit with the morphology of the alimentary tract. The present paper deals with a study of the food, feeding and alimentation of *Mugil tade* Forsk., on the lines indicated above.

II. FOOD AND FEEDING HABITS

(i) *Résumé of existing knowledge on the food of mullets*

Sarojini (1951) has reviewed in some detail the literature on the food and feeding habits of grey mullets which, as pointed out by her, are variously described as plankton-feeders, herbivores, omnivores, slime-feeders, foul-feeders, etc. Günther (1850 and 1881) first observed that the fishes of this genus fed on organic substances mixed with sand or mud, an observation later corroborated by Cunningham (1891),

Linton (1904), Jordan (1905) and Hornell (1911). Hornell (*op. cit.*), however, added that they feed voraciously on occasions upon shoals of small crustaceans. Jacot (1920), in agreeing with Linton's (*op. cit.*) views, explained that the stomach contents of the adult fish consisted roughly of 40% sand and mineral matter, and 60% vegetable and animal matter. He found that the juveniles of *M. cephalus*, unlike those of the allied *M. curema*, had an exclusive diet of crustaceans, mainly copepods. The findings of Herre and Mendoza (1929), Ishida (1935), Ghazzawi (1933 and 1935), Smith (1935), Hora (1938), Hiatt (1944), Pillay (1948) and John (1948) have all indicated that the mullets are herbivorous. Of these, the works of Ghazzawi and Hiatt are worth special mention. Ghazzawi (1933) inferred from a study of the gut contents of a total of 120 specimens of *M. cephalus* and *M. capito* caught during three successive months (September to November) from Egyptian waters, that 'the main food if not all, of the adult and growing fish at any rate, is of vegetable origin and other algal plants'. The histological studies made by him (1935) showed that gastric glands are present in the stomach of *M. capito*. Hiatt (*op. cit.*) concluded from a study of the gut contents of *M. cephalus* from Hawaiian fish ponds that the fish subsist primarily on littoral diatoms and blue-green algae.

The findings of certain workers suggest the possibility of the grey mullets being omnivorous. Beavan (1877) stated that mullets fed on 'soft organic substances or very small animals'. Kyle (1926) observed that mullets fed on the mud or detritus containing the remains of plant and animal bodies that have settled to the bottom; while Norman (1937) found that decomposed animal and vegetable matter contained in mud formed the food of mullets. Lin (1940) mentioned that *M. cephalus* fed on organic matter and small crustaceans which live or hide in the muddy bottom of ponds. Remarks of Orton (1926) and the statement of Roughley (1925) (quoted by Orton) indicate even the possibility of mullets being carnivorous. The record of foraminiferan shells from the stomachs of mullets (Gnanamuthu, 1943) only indicate that they feed on the bottom of littoral areas.

Mookerjee, Ganguly and Mazumdar (1946) found in 10 specimens of *M. belanak* that the stomachs contained mixed food. Though algae formed 50% of the gut contents, the percentage of animal matter was as high as 40%. They found in the stomachs of the same number of *M. parsia* examined during the same months only algae and sand mixed with mud, thus showing marked difference from *M. belanak* in its food habits. Mookerjee, Ganguly and Sircar (1946) inferred that *M. parsia* fed on both vegetable and animal matter at the bottom, except in a transitional stage between 19 mm. and 22 mm. (total length), 'when they roam at the surface' and feed on surface plankton. Basu (1946) concluded from an examination of 200 specimens of *M. parsia* that in the early stages they were entirely plankton feeders and began feeding on algae and other coarser matter after attaining a size of over an inch in length. Devanesan and Chidambaram (1949) found that the mullets fed on sea-weeds and planktonic organisms, generally larvae of bristle-worms (polychaetes), and larval molluscs.

A different opinion on the food of mullets has been expressed by certain other workers. From a study of the gut-contents of 12 species of mullets from Madras, Chacko and Venkatraman (1945) inferred that they were chiefly plankton-feeders, an inference which Jacob and Krishnamurthy (1948) have corroborated. A similar conclusion is drawn by Devanesan (1942) in reference to *M. waigiensis* which feeds on *Trichodesmium* and the fishery for which is to a certain extent governed by the abundance of this alga. Jacob and Menon (1947) found *M. parsia* and *M. waigiensis* feeding on copepods on the West Coast. The statement of Schultz and Stern (1948) that the mullets at night swim in schools close to the tropical shores to feed upon microscopic organisms near the land, may also be taken as supporting this view.

Moses (1941) included mullets among foul-feeders as they feed on 'odds and ends of decayed faecal matter'. A still different view has been held by some workers.

Kesteven (1942) was unable to find any 'discrete identifiable material' in the stomach of the Australian Mullet, *M. dobula*, and therefore suggested that they may be bottom-feeders making use of accumulations of detritus in lakes and estuaries.*

As the above résumé shows the precise nature of the food of mullets has not been fully elucidated. The present work was undertaken in order to reconcile the contradictory opinions on this problem which called for special attention, in view of the need for the adoption of scientific methods for increasing the right type of food for mullets in farms. The author's preliminary note (Pillay, 1950) on the subject is elaborated in the present paper.

(ii) *Material*

It was originally proposed to make a comparative study of the food of all the local mullets, but it was later decided to study completely the biology of one species, *Mugil tade* Forsk. (known as 'Bhangon' in Calcutta and nearby places and 'Dhoka' in the Midnapore Dist.) as part of a scheme of investigations now in progress. Highly favoured on account of its tasty flesh and the absence of fine bones, *M. tade* occurs in marine and estuarine environments and is cultured in brackishwater farms (Hora and Nair, 1944) and in freshwater tanks (Pillay, 1949). As the fish lives in different types of ecological surroundings, it was considered desirable to study the variations in its food habits. Regular monthly collections of specimens were made from four representative centres, namely the sea at Junput (Contai-Midnapur Dist.), the Matla Estuary at Port Canning, the enclosed brackishwater farm at Ghutiari Sharif (24-Parganas), and certain freshwater tanks at Junput. 483 specimens covering all the available size groups were examined in detail. The earliest procurable stage of *M. tade*, 15 mm. in length, was collected in the month of August. Specimens up to the fifth stage of maturity were obtained for examination of gut contents, but oozing specimens which are believed to migrate to the sea during the monsoons for breeding, or spent fish, could not be secured as fishing in the sea was practically closed during the rainy season. In the absence of a suitable surf vessel, it was not possible to collect material from the mouth of the estuary or from the offshore waters of the sea during this part of the year. While fish of some size group or other were available all through the year on the sea coast, their availability in the estuary was seasonal. In the brackishwater farm and freshwater tanks also, fishing was seasonal; and fishing by cast-net during other parts of the year did not always succeed in securing adequate numbers of specimens for study. The data discussed in this paper, therefore, relate only to the seasons of availability of the fish in these localities.

(iii) *Methods*

Fish were collected at regular monthly intervals from sampling centres. Except at Port Canning, where specimens had to be purchased from the market, samples were obtained directly from the fishermen at the fishing centres. The time of catch, nature of fishing gear, atmospheric conditions, etc., were noted in the field. In the initial stages of the work surface plankton was also collected, by means of a bolting-silk tow-net from the sea and the estuary and with a smaller muslin net from the farm and tanks. But, since it was soon found that the organisms in the surface plankton did not bear any relation to the gut contents, this was discontinued. Instead, samples of the benthic flora and fauna were collected, in order to correlate them with the food of the fish.

The study of the food and feeding habits was taken up as a part of a comprehensive study of the biology of the fish, involving a detailed study of samples.

* In a later contribution Thomson (1951) has reported the presence of diatoms and other constituents of the flora and fauna in the gut contents. In fresh waters they were observed to depend on green algae, to some extent.

So it was not always possible to examine the gut contents in the fresh condition in the field, which, in all cases, lay far off from the laboratory. The entire fish were therefore fixed in 5% formaldehyde and brought to the laboratory. Large fish were generally cut open in the field itself and the whole viscera fixed in 5% formaldehyde. In the laboratory the extent of the feed was determined by the degree of distension of the stomach and the amount of food it contained. Although the limitations of such an estimate have been discussed by Job (1940), this was the only practicable method that could be adopted for the purpose in the present investigation. The condition of feed was classified as (i) gorged (the stomach swollen with food, the cardiac part being well expanded in size), (ii) full, (iii) $\frac{3}{4}$ full, (iv) $\frac{1}{2}$ full, (v) $\frac{1}{4}$ full, (vi) a little (containing a little food) and (vii) empty. The stages of maturity of the specimens were also noted.

The gut contents were thoroughly washed into petri-dishes or watch glasses containing adequate quantities of water for dilution and examined under the microscope. Generally they contained mud mixed with algal matter, which could not easily be separated. The analysis of the gut contents presented many difficulties. The decayed organic matter and the algal matrix that mullets eat, do not lend themselves to a numerical method of analysis as it is not possible to count the fragments of vegetable matter in a finely comminuted state. By volumetric analysis, however, it was found possible to assess, with a fair amount of accuracy, the composition of these items. McAtee (1912), Collinge (1927), etc., have advocated the adoption of volumetric analyses in food studies, and according to Hynes (1950), until dietetic values of food species are known, volume forms a satisfactory basis for assessment, when the food of the animal investigated consisted of vegetable matter, wholly or in part.

Attempts were made to separate the chief constituents of the gut contents, so that a correct volumetric assay could be made. Since the gut contents of mullets always consisted of a large proportion of mud it was considered that the methods generally employed for the study of the bottom sediments in water analysis, might be suitable for the purpose. The method of examination of bottom sediments developed by the United States Public Health Service during its investigation of the Ohio River (quoted by Whipple, 1927) consists of placing mud in a vessel like a 'moist chamber' which has perpendicular sides, running tap water into it and agitating and rotating the vessel until the water is very turbid with mud in suspension, and then filtering through a close-meshed sieve. More tap water is added and the process repeated as often as necessary until all the mud has been passed through the sieve whose fine meshes retain the organisms. The catch is transferred to a vessel of clear water for convenient study. The Sedgwick-Rafter method of concentration and examination of bottom sediments most frequently used in sanitary water analysis is recommended in 'Standard Methods of Water Analysis' (quoted by Whipple, 1927). This method consists briefly of the following processes: the filtration of a measured quantity of the sample through a layer of sand which retains the organisms; the separation of the organisms from the sand by washing it with a small measured quantity of filtered or distilled water and fractional decanting; the microscopical examination of a portion of the decanted fluid; the enumeration of the organisms found therein; and the calculation of the number of organisms in the sample of water examined. This method was tried and found to be suitable, to a limited extent, to separate the different organisms. But the presence of large quantities of decayed organic matter made this work extremely difficult as they could not easily be separated from the algae and diatoms, and the algal growth could not be fully separated from the sand grains. However, the proportion of sand grains to organic matter could correctly be determined by oxidizing a known quantity of the gut contents by ignition, or by adding hydrogen peroxide and gently heating it over a spirit lamp. But as, in practice, it was found rather difficult to follow these methods in the study of a large number of samples,

Pearse's method (1915) was adopted for general work, and the filtration and ignition methods were occasionally used to test the accuracy of results thus obtained. Due to the difficulty experienced in separating the constituents of the gut contents, it was not possible to employ the displacement method recommended by Savage (1931) and Ritchie (1937).

The 'occurrence method' of analysis in which the number of fish containing each item of food in the guts is expressed as a percentage of the total number of fish examined (Hynes, *op. cit.*) serves as a useful aid to understand the prevalence of the food components in the diet and their relative importance. In the present work the data were analyzed by this method also.

A considerable number of specimens examined had their stomachs empty. Afflalo and Martson (1904) have observed that many fishes have the habit of throwing up their last meal when captured. Ogilvie (1927) found that the shock of capture did not induce post-larval herrings to throw out food. The present author, like Job (1940), found no direct evidence in support of the observations of Afflalo and Martson (*op. cit.*).

Hess and Rainwater (1939) experimentally found that 'a difference does exist in the rate of digestion of the different kinds of organisms' and this, they recommended, should be taken into consideration in evaluating stomach contents of fishes. The algae and diatoms which constituted the main distinguishable items of sustenance of *M. tade* were usually found to be entire and undigested among the stomach contents; and so this factor was not taken into consideration in the present study. The contents of the duodenum and the anterior regions of the intestines were generally in a semi-digested state and that of the rectum consisted of an unidentifiable mass mixed with good quantities of sand. In the estimation of the percentage volumetric composition, the total gut contents of the individual, including sand grains, were taken as a unit, as this was found to facilitate a more satisfactory estimation.

From the detailed records of the list and the percentage composition of the food components of individuals examined, monthly average percentages were calculated for each type of locality. From this the total average percentage composition of the food was computed for different environments.

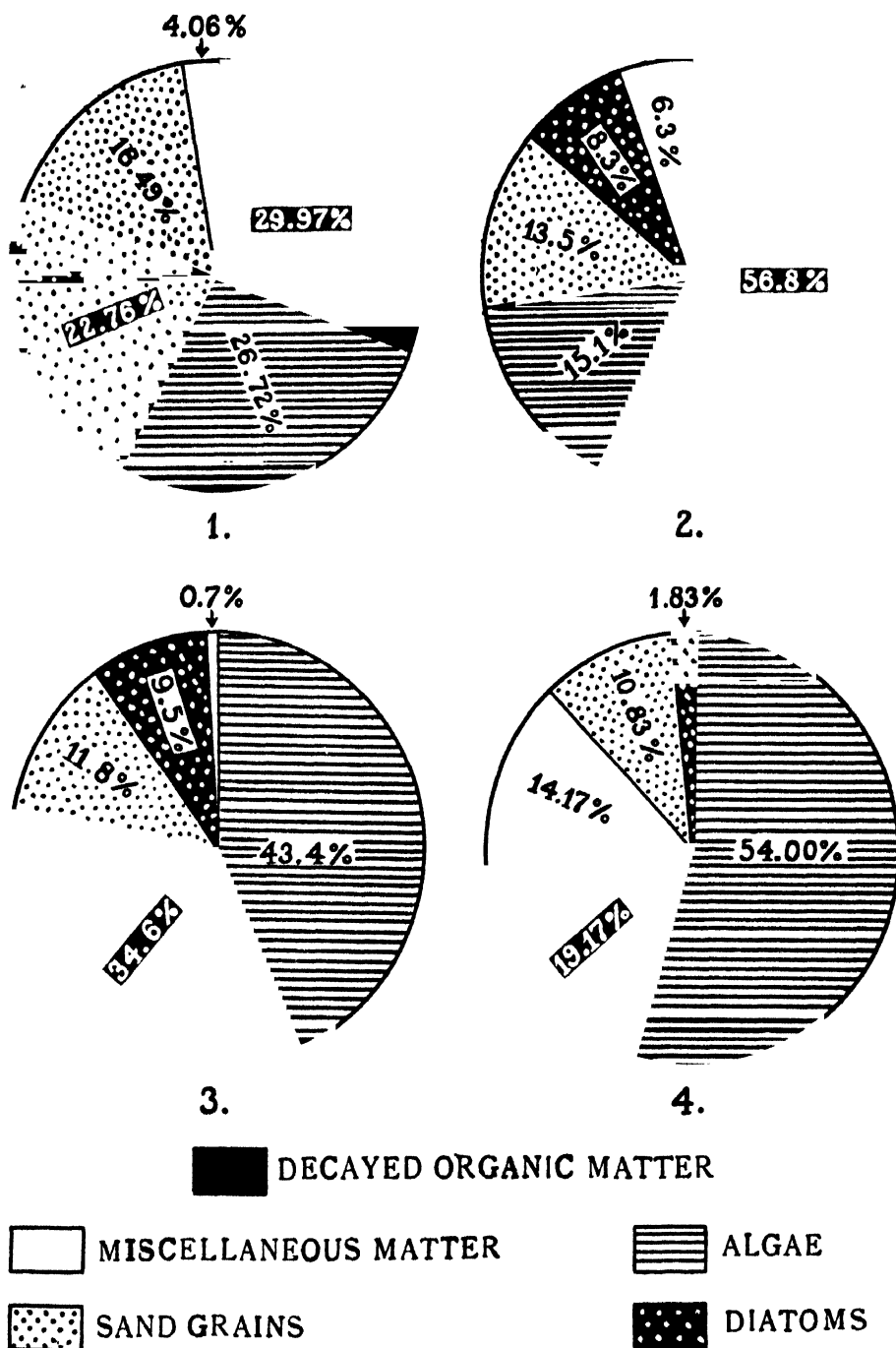
The gut contents of fish from all the four types of environments showed monthly variations in their composition. Such fluctuations in the composition of food had been commented on by Yarrel (quoted by Sims, 1883) and observed in Indian fishes by Job (1940) and Menon (*op. cit.*).

As Lagler (1949) has pointed out, distinction has to be made between food habits or food eaten, and feeding habits; the latter being the behaviouristic aspects of feeding. Food studies based only on the contents of digestive tracts or droppings merely show what an animal will eat. Such facts when correlated with feeding habits and ecological factors may prove of great value in fishery management. Attempts were made during the present investigation to ascertain the feeding habits of the fish by direct observations in the field and in aquaria.

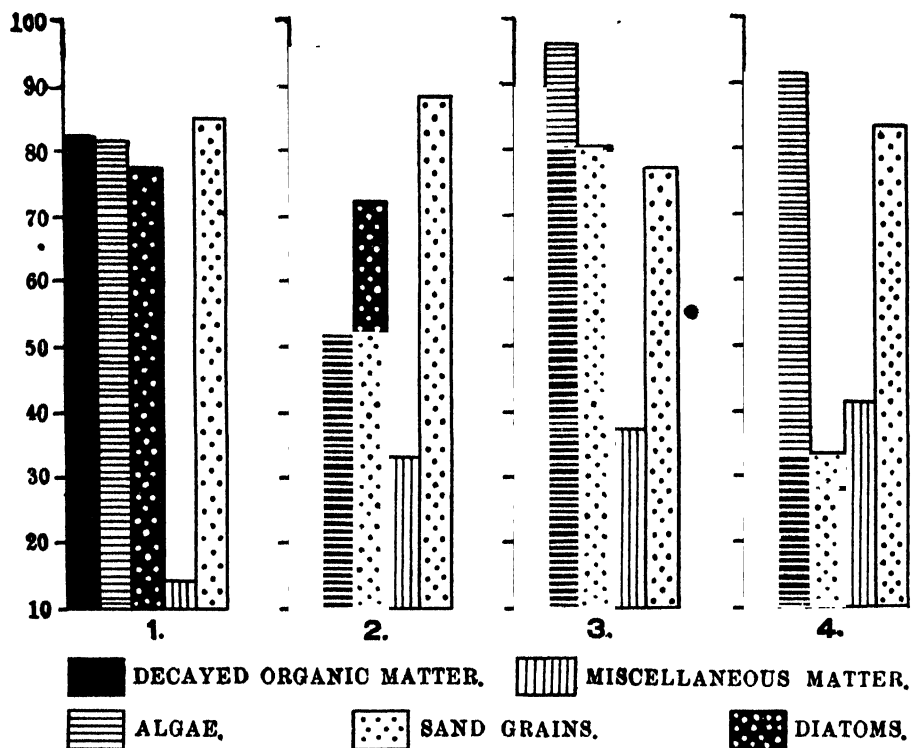
(iv) Observations on Food Habits

1. Marine Environment

Mugil tade is caught in considerable numbers along the Contai coast and from the waters off Sagar Islands. At Contai they are mainly caught in stake nets known as *Bher-jal* fixed along the shore during the fishing season which extends from October to January. During the 'off season' they are caught in a type of hand-seine known as *Katti-jal*. The fishermen believe that the mullets come to the shore with the high tide. Fry of the species ranging from 15 mm. to 29 mm. in total length were available in the creeks and tidal springs during July-August. In winter months the catches consisted mainly of specimens 39 mm. to 367 mm. in



TEXT-FIG. 1. Pie diagrams showing the volumetric composition of the food of *Mugil tade* Forsk. in different environments. (1) Sea, (2) Estuary, (3) Brackishwater Farm, (4) Fresh-water tanks.

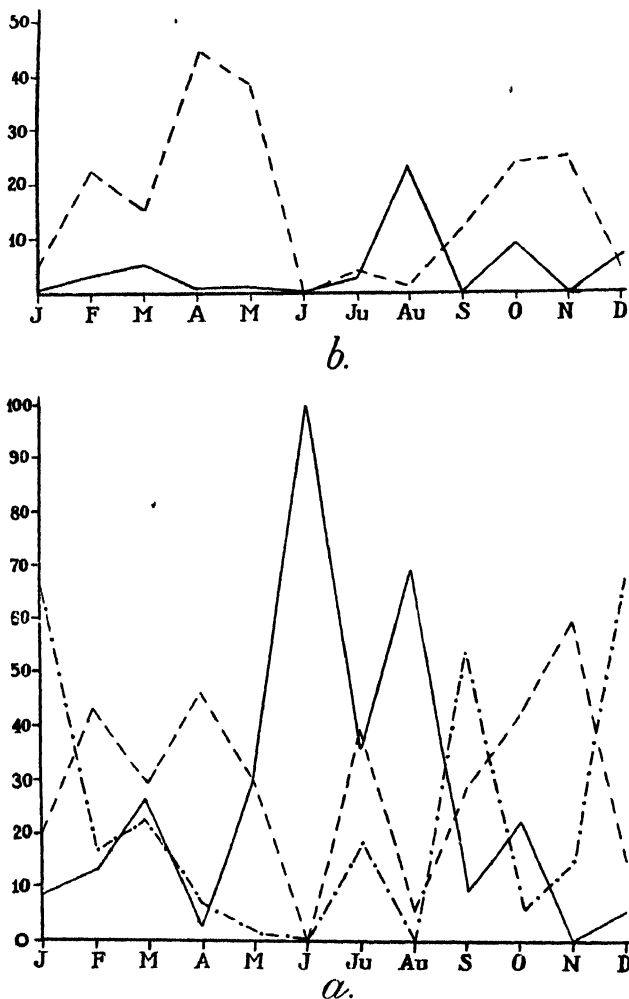


TEXT-FIG. 2. Histograms showing the prevalence of each item of food in different environments. (1) Sea, (2) Estuary, (3) Brackishwater Farm, (4) Freshwater tanks.

length. During the monsoons, large females 400 mm. to 506 mm. in length with maturing ovaries were sometimes caught in the hand seines. But this being the 'off season', when large nets which need the help of boats for operation are not employed, specimens of fish are not easily available.

One hundred and ninety-one specimens ranging from 15 mm. to 506 mm. in length were examined. The time of catch of these samples varied with the tide timings, as fishing was dependent on tides. Of the above, 6% were fry 15 mm. to 29 mm. in length. About 14% were males and 6% females, and the sex of the rest could not be distinguished owing to their immaturity. Of the males, 65% were immature and the rest had fairly developed gonads. Among the females 30% had gonads in IV and V stages of development. Table I shows the seasonal fluctuations in the condition of feed of the fish examined. This table reveals a marked increase in feeding activity of the adult fish during the months October to January, when 75%, 100%, 53.6% and 95.8% of the fish respectively had stomachs full or gorged with food. None of the specimens had an absolutely empty stomach. This bears close correlation with the algal bloom that occurs in these waters after the rainy season and persists throughout the winter. It may be noted that in the case of fry, almost all had their stomachs in full or gorged state of feed during August-September.

Analyses of the gut contents of specimens from marine environments show that decayed organic matter, algae and diatoms together form its main food. Sand grains and miscellaneous animal remains appear to be taken in automatically along with the food items associated with them, when the fish feeds on the bottom or littoral areas. The gut contents consisted of approximately 30% decayed organic



TEXT-FIG. 3. Graphs showing the fluctuations in the volume of different items of food consumed during the various months in the marine environment. (a) Decayed organic matter represented by broken line, algae by continuous line and diatoms by dots and dashes. (b) Miscellaneous matter represented by continuous line and sand grains by broken line.

matter, 27% algae and 23% diatoms. The miscellaneous items constituted about 4% of the stomach contents and the remaining 16% consisted of fine sand grains. 82.5% of the specimens examined, had decayed organic matter in the guts, 81.9% had algae and 77.3% had diatoms.

Table II gives the quantitative and qualitative analytical data for the different months, and Table III the prevalence of each item of food in the gut contents assessed by the occurrence method. Text-figs. 3a and 3b show the fluctuations in the composition of the food during different months.

Decayed Organic matter.—This consisted mainly of a decayed slimy mass of unidentifiable plant matter. The shallow littoral of the Contai coast has extensive mud deposits of thick ooze covered by a layer of organic matter, exposed at low tides. Text-fig. 3a shows that the maximum quantity of this type of food occurred in November, the next two periods of abundance being April and July. An

TABLE I

Statement showing the monthly frequency (in percentage) in the 'Condition of Feed' of samples examined from the Sea (Junput)

Months	Frequency in percentage of specimens with stomachs :							
	Gorged	Full	$\frac{3}{4}$ full	$\frac{1}{2}$ full	$\frac{1}{4}$ full	With a little food	With very little food	Empty
January ..	77.0	18.8	..	..	..	4.2	..	..
February ..	16.0	16.0	12.0	8.0	36.0	8.0	4.0	..
March ..	..	..	..	60.0	40.0	..	..	..
April ..	..	25.0	50.0	..	..	25.0	..	..
May ..	56.0	44.0	..	..	..	..	..	..
June ..	..	..	..	..	..	100.0	..	..
July* ..	22.2	16.7	11.1	16.7	22.2	11.1	..	..
August* ..	..	92.3	..	7.7	..	..	..	..
September* ..	29.4	23.5	11.8	11.8	11.8	..	11.7	..
October ..	15.0	60.0	..	20.0	..	5	..	..
November ..	..	100.0	..	..	..	..	..	..
December ..	7.2	46.4	14.3	21.4	7.2	3.5	..	..

* Indicates the months when fry predominated in the samples examined.

examination of the graph will show that when the percentage of algal food was high, decayed matter consumed was very low. Whether this was due to the relative abundance of algae in the locality or to selective feeding by the fish, is not known. However, the experimental data discussed in a later section of this paper, appear to show that the fish prefers either decaying or fresh algae when available and only when it is not available do they take to decayed macrovegetation. From Table III it will be seen that decayed organic matter formed a regular constituent of the diet and occurred in the guts of most of the specimens examined. The gut contents of young specimens 15 mm. to 29 mm. in length were completely devoid of decayed matter. Another important feature noticed is that quantities of sand taken into the stomach increase with the growth of the fish.

Algae (*Chlorophyceae* and *Myxophyceae*).—Next to decayed matter, fresh growing algae formed the most important item of food, thick patches of which may often be seen on the mud deposits and in the shallow depressions of the tidal zone of the shores. A preliminary comparative study showed that it was this very type of algal growth, that the fish consumed. Species of *Oscillatoria*, *Anabaena* and *Enteromorpha* were the more common algae identified from the gut contents. Of these, *Oscillatoria* sp. was relatively the most abundant, during the months of October, December and February. *Symploca*, *Polysiphonia*, *Chaetomorpha*, *Cosmarium*, *Cladophora*, and algal spores formed the other constituents of the algal food.

In June and August algae were consumed in large quantities, the percentage of algae in the stomach contents being 100 in June and about 70 in August. In November algal food was completely absent in the gut contents and in April it formed only about 2.3% of the bulk. The gut contents of fry 15 mm. to 29 mm. in size consisted mainly of algae. During the major part of the year algae occurred as a regular item of food (*vide* Table III).

Diatoms.—Mann (1921) has pointed out that many species of diatoms have been observed to live principally or wholly on the sea bottom. These diatoms grow in patches on the bottom or on the algal matrix and decayed matter covering the mud flats, as revealed in abundance in the scoopings from the littoral regions.

TABLE II
The qualitative and quantitative composition of the Gut contents of *M. tade* from Marine Environment

	January		February		March		April	
	%age	Food components	%age	Food components	%age	Food components	%age	Food components
Decayed matter ..	19.65	..	43.7	..	29.97	..	46.25	..
Algae (Chlorophyceae and Myxophyceae).	8.5	<i>Oscillatoria</i> <i>Polysiphonia</i> <i>Chaetomorpha</i>	13.2	<i>Oscillatoria</i> <i>Enteromorpha</i> <i>Cosmarium</i>	26.72	<i>Oscillatoria</i> <i>Enteromorpha</i>	2.25	<i>Oscillatoria</i> <i>Cosmarium</i>
Diatoms ..	66.81	<i>Cyclotella</i> <i>Coscinodiscus</i> <i>Gyrosigma</i> <i>Pleurosigma</i> <i>Nitzschia</i> <i>Surirella</i>	17.7	<i>Cyclotella</i> <i>Coscinodiscus</i> <i>Rhizosolenia</i> <i>Bacteriastrium</i> <i>Triceratium</i> <i>Grammatophora</i> <i>Synedra</i> <i>Thalassionema</i> <i>Gyrosigma</i> <i>Pleurosigma</i> <i>Diploneis</i> <i>Navicula</i> <i>Pinnularia</i> <i>Amphora</i> <i>Cymbella</i> <i>Nitzschia</i> <i>Surirella</i>	22.76	<i>Cyclotella</i> <i>Coscinodiscus</i> <i>Synedra</i> <i>Gyrosigma</i> <i>Pleurosigma</i> <i>Diploneis</i>	6.5	<i>Fragilaria</i> <i>Synedra</i> <i>Pleurosigma</i> <i>Diploneis</i> <i>Navicula</i> <i>Nitzschia</i> <i>Surirella</i>
Miscellaneous matter ..	..	..	2.7	Copepod remains. Copepods Appendages of Daphnia. Larval bivalves	4.06	Copepod remains.	..	..
Sand grains ..	5.04	..	22.7	..	16.49	..	45.0	..

TABLE II (Contd.)
The qualitative and quantitative composition of the Gut contents of *M. tade* from Marine Environment

	May		June*		July		August	
	%age	Food components	%age	Food components	%age	Food components	%age	Food components
Decayed matter Algae (Chlorophyceae and Myxophyceae).	29.5 30.0	<i>Oscillatoria</i> <i>Cosmarium</i> <i>Cladophora</i>	.. 100.0	<i>Oscillatoria</i> <i>Cosmarium</i>	39.4 35.3	<i>Oscillatoria</i> <i>Cosmarium</i> <i>Cladophora</i>	5.38 69.46	<i>Oscillatoria</i> <i>Enteromorpha</i> <i>Cladophora</i> Algal spores
Diatoms	1.625	<i>Asterionella</i> <i>Biddulphia</i> <i>Diploneis</i> <i>Surirella</i>	..	..	18.6	<i>Coscinodiscus</i> <i>Synedra</i> <i>Asterionella</i> <i>Navicula</i> <i>Cymbella</i>	0.31	<i>Coscinodiscus</i> <i>Pleurosigma</i> <i>Navicula</i>
Miscellaneous matter	0.125	<i>Ceratium</i>	..	..	2.8	<i>Polychaete</i> moults.	23.62	Copepod appendages. Copepods Crustacean larvae. Cladocerans Mysids <i>Polychaete</i> moults.
Sand grains	38.75	..	..	..	3.9	..	1.23	..

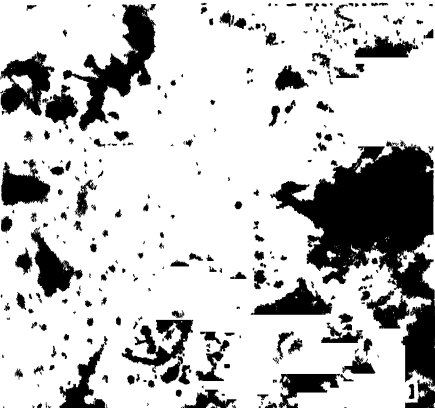
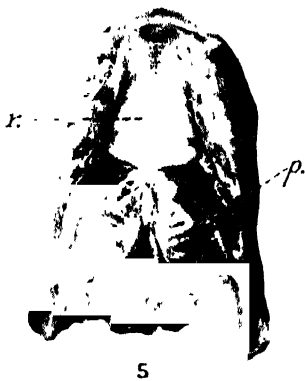
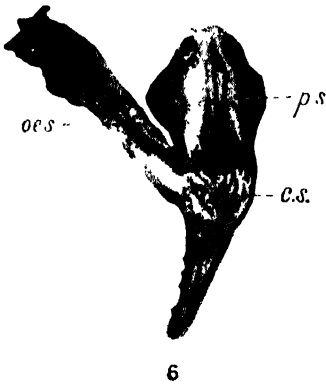
* The samples examined during this month consisted entirely of juveniles.

TABLE II (Contd.)
The qualitative and quantitative composition of the Gut contents of *M. tade* from Marine Environment

	September		October		November		December	
	%age	Food components	%age	Food components	%age	Food components	%age	Food components
Decayed matter	28.67	..	42.17	..	60.0	..	15.0	..
Algae (Chlorophyceae and Myxophyceae).	9.2	<i>Oscillatoria</i> <i>Cosmarium</i>	20.33	<i>Oscillatoria</i> <i>Symploca</i> <i>Anabaena</i> <i>Polysiphonia</i> <i>Chaetomorpha</i> <i>Enteromorpha</i> <i>Cosmarium</i>	..	..	5.7	<i>Oscillatoria</i> <i>Enteromorpha</i> <i>Cosmarium</i>
Diatoms	50.4	<i>Coscinodiscus</i> <i>Synedra</i> <i>Thalassionema</i> <i>Asterionella</i> <i>Diploneis</i> <i>Navicula</i> <i>Amphora</i> <i>Cymbella</i>	5.1	<i>Cyclotella</i> <i>Coscinodiscus</i> <i>Synedra</i> <i>Gyrodinium</i> <i>Pleurosigma</i> <i>Diploneis</i> <i>Pinnularia</i> <i>Cymbella</i>	15.0	<i>Cyclotella</i> <i>Coscinodiscus</i> <i>Surirella</i>	68.3	<i>Cyclotella</i> <i>Coscinodiscus</i> <i>Biddulphia</i> <i>Grammatophora</i> <i>Synedra</i> <i>Mastogloia</i> <i>Gyrodinium</i> <i>Pleurosigma</i> <i>Navicula</i> <i>Nitzschia</i> <i>Surirella</i>
Miscellaneous matter .. ..	..	..	8.7	Zoea larvae Nauplius larvae Polychaete moults.	..	..	6.7	Copepods Polychaete moults.
Sand grains	11.73	..	23.7	..	25.0	..	4.3	..

TABLE III
Prevalence (percentage) of Food Components of M. tade in the Marine Environment

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Decayed matter ..	100.0	100.0	82.5	100.0	100.0	..	100.0	7.7	100.0	100.0	100.0	100.0
Algae (Chlorophyceae and Myxophyceae).	95.8	100.0	84.6	100.0	100.0	100.0	94.4	81.9	60.5	88.2	..	77.4
Diatoms ..	93.8	100.0	77.3	100.0	100.0	..	55.6	15.4	100.0	88.2	100.0	96.8
Miscellaneous matter ..	..	33.3	12.5	..	14.4	..	11.1	61.5	..	17.6	..	22.6
Sand grains ..	95.8	100.0	100.0	100.0	100.0	..	61.1	7.7	100.0	100.0	100.0	96.8



The fish graze on these growths of diatoms. Several species belonging to 20 genera have been observed in the stomach contents. Of these *Cyclotella*, *Coscinodiscus*, *Synedra*, *Gyrosigma*, *Pleurosigma*, *Biddulphia*, *Diploneis*, *Navicula*, *Cymbella* and *Surirella* formed the more important genera. *Rhizosolenia*, *Bacteriastrum*, *Triceratium*, *Grammatophora*, *Fragilaria*, *Thalassionema*, *Asterionella*, *Mastogloia*, *Pinnularia*, *Amphora* and *Nitzschia* were the other forms identified. *Surirella*, together with *Coscinodiscus*, *Navicula*, *Cymbella* and *Diploneis* formed the major constituents of the stomach contents in January, when a large percentage of the fish were found to have the stomachs well gorged. *Coscinodiscus* predominated in the gut contents in February. In several specimens examined in the month of May the stomachs contained nothing but *Asterionella japonica* mixed with sand grains. *Pleurosigma* formed a very predominant item of food in November. In December and January the diatoms constituted 68.3% and 66.81% respectively of the food consumed by 96.8% and 93.8% of the fish examined. When the next peak occurred in September, 50.4% of the food eaten by all the fish consisted of diatoms. Diatoms were relatively scarce in the stomach of fish during April, May, June, August and October. Plate XXXIII, Fig. 1, shows a sample of the gut contents from the marine environment in which diatoms predominated.

Miscellaneous Matter.—The important constituents of this item were copepod and cladoceran appendages, moults of polychaete worms, nauplius and zoea larvae and mysids. It is doubtful whether these could be termed food of the fish, in the right sense of the term. During a considerable part of the year they did not occur in the stomach contents (*vide* Table II). Even during the rest of the year, at no time were they found in more than 33.3% of the guts examined in full grown specimens. It is a moot point whether the fish derives any nutriment from the moults of worms or the exo-skeleton of crustacean appendages. The contents of the rectum were examined, but since it contained only a well ground pulpy mass, the exact nature of the constituents could not be fully determined. Apparently, these miscellaneous items of food are accidentally swallowed by the fish, while feeding on detritus, algae and diatoms. Their low percentage and occasional occurrence presumably point to this conclusion. However, fry often feed on appreciable quantities of copepods, cladocerans and mysids.

The miscellaneous items formed on an average, about 4% of the total food consumed. The maximum quantity of such matter occurred in the month of August (23.62%) and small quantities in February (2.7%), July (2.8%), October (8.7%) and December (6.7%). They were very scarce (0.125%) in May and totally absent during other months. Mysids formed the most predominant item of this category in the gut contents of fry examined in August. Other animalcules such as larval bivalves were also seen to have been consumed by them. As stated by Rabanal (1949) the algal complex growing in brackish or saltwater areas has usually associated with it different forms of animal constituents like copepods, ostracods, larval molluscs, etc. Obviously, while the fish consumed algae these animalcules may also have been accidentally taken in.

Sand grains.—Sand grains formed a regular item in the gut contents of all adult fish. Table III shows that during all the months except June, July and August, almost all the specimens examined had sand grains in the gut contents. They were invariably seen mixed with other types of food matter. It is of interest to note that only very fine grains of sand appear in the guts. These are, obviously what are left after the coarser particles are sieved out by the pharyngeal filtering apparatus. On the average, sand grains formed about 16% of the total gut contents. The largest quantity of it appeared in April and May, when it constituted 45% and 38.75% of the gut contents respectively. It appeared in moderate quantities in February (22.7%), October (23.7%), September (11.73%), and November (25%). Small quantities occurred in July (3.9%), August (1.23%), December (4.3%), and January (5.04%).

2. Estuarine Environment

Port Canning on the river Matla is an important mullet fishing and assembling centre. Mulletts are fished here largely with the *Behundi-jal* (Naidu, 1939) and cast nets. Fish caught lower down the estuary including those taken in *Charpatta-jal* and *Khalpatta-jal* and fish cultured in *bheris* are brought to this centre in boats, to be railed to Calcutta. For the purposes of this investigation, only the local catches were utilized, as the correct source of supply of fishes brought from other areas could not be ascertained.

One hundred and nine specimens ranging from 18 mm. to 325 mm. caught in the mornings and evenings over a period between May and December were examined. A majority of them being immature, their sex could not be distinguished. Larger specimens were only rarely obtained in the catches from this area. Specimens 250 mm. to 325 mm. in length were obtained in June and young ones 34 mm. to 51 mm. long were also common during this month. Table IV shows the condition of feed of the specimens examined. The feeding activity appears to have been more vigorous during October-November. In September a considerable percentage of specimens was found, in which the stomach was either empty or with only 'a little' or 'very little' food in them. During September the percentages of algae and diatoms in the gut contents were low. Field observations indicated that the intensity of feeding varied with the abundance of the favourite food items on the illotrophic layers in the habitats of the fish.

The qualitative and quantitative analyses of data for the estuarine environment are presented in Table V, the prevalence of food components in Table VI, and the monthly fluctuations in the volumetric composition of food in Text-figs. 4a and 4b. These show that decayed organic matter formed the main constituent of the food in the estuary, being as much as 56.8% of the total food consumed. 94.2% of the guts examined contained this item. Algae formed about 15.1% and diatoms 8.3% of the total gut contents, and 52.1% and 72.2% respectively of the fish examined had eaten these. Miscellaneous items constituted 6.3% and sand grains 13.5% of the food consumed. 88.4% of the guts examined had sand grains in them.

TABLE IV

Statement showing the monthly frequency (in percentage) in the 'Condition of Feed' of samples examined from the Estuary (Port Canning)

Months	Frequency in percentage of specimens with stomachs :							
	Gorged	Full	$\frac{3}{4}$ full	$\frac{1}{2}$ full	$\frac{1}{4}$ full	With a little food	With very little food	Empty
May	100.0	..	..	..	..
June	..	17.6	5.9	32.4	29.4	..	11.8	2.9
July	100.0	..	..	..	..
August	..	20.6	14.7	29.5	20.6	2.9	5.9	2.9
September	..	4.8	4.8	19.0	..	33.3	4.8	33.3
October	..	11.1	22.2	22.2	..	33.4	..	..
November	..	33.3	22.3	33.3	..	11.1	..	..

Decayed organic matter.—The Gangetic system is noted for the enormous quantities of silt it washes down, and all along the margins of the estuaries can be seen thick deposits of detritus. The fish sucks in considerable quantities of this.

TABLE V
The Qualitative and Quantitative composition of the Gut contents of *M. tade* from Estuarine Environment

	May		June		July		August	
	%age	Food components	%age	Food components	%age	Food components	%age	Food components
Decayed matter ..	85.00	..	50.06	..	56.80	..	28.90	..
Algae (Chlorophyceae and Myxophyceae)	..	..	11.85	<i>Oscillatoria</i> <i>Phormidium</i> <i>Symptloca</i> <i>Microcoleus</i> <i>Anabaena</i> <i>Protococcus</i> <i>Enteromorpha</i> <i>Polysiphonia</i>	15.10	<i>Oscillatoria</i> <i>Anabaena</i> <i>Protococcus</i> <i>Enteromorpha</i> <i>Polysiphonia</i>	29.00	<i>Gloeocapsa</i> <i>Oscillatoria</i> <i>Lyngbya</i> <i>Symptloca</i> <i>Microcoleus</i> <i>Anabaena</i> <i>Chaetomorpha</i> <i>Enteromorpha</i> <i>Bulbochaete</i> <i>Polysiphonia</i>
Diatoms ..	5.00	<i>Coscinodiscus</i> <i>Nitzschia</i> <i>Navicula</i>	13.15	<i>Cyclotella</i> <i>Coscinodiscus</i> <i>Rhizosolenia</i> <i>Synedra</i> <i>Asterionella</i> <i>Gyrosigma</i> <i>Pleurosigma</i> <i>Diploneis</i> <i>Navicula</i> <i>Pinnularia</i> <i>Amphora</i> <i>Tracheneis</i> <i>Surirella</i> <i>Nitzschia</i>	8.30	<i>Cyclotella</i> <i>Coscinodiscus</i> <i>Synedra</i> <i>Gyrosigma</i> <i>Diploneis</i> <i>Surirella</i>	13.70	<i>Tabellaria</i> <i>Synedra</i> <i>Mastogloia</i> <i>Gyrosigma</i> <i>Diploneis</i> <i>Navicula</i> <i>Pinnularia</i> <i>Amphora</i> <i>Gymbella</i> <i>Surirella</i>
Miscellaneous matter ..	2.00	Polychaete moults.	7.24	Copepod appendages. Copepods Cladocerans	6.30	Copepod appendages. Polychaete moults.	1.70	Polychaete moults.
Sand grains ..	8.00	..	17.70	..	13.50	..	26.70	..

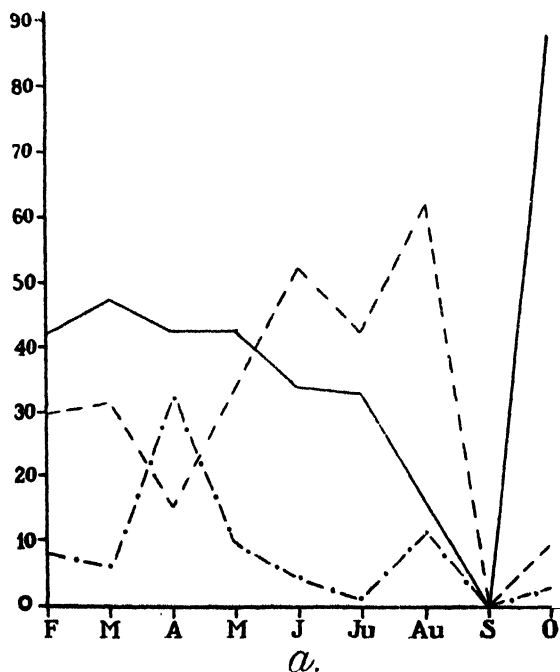
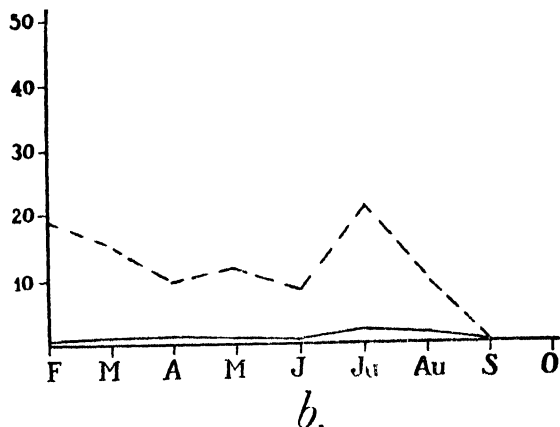
TABLE V (Contd.)
The Qualitative and Quantitative composition of the Gut contents of M. tade from Estuarine Environment

	September		October		November	
	%age	Food components	%age	Food components	%age	Food components
Decayed matter	63.77	..	25.89	..	87.22	..
Algae (Chlorophyceae and Myxophyceae).	10.12	<i>Oscillatoria</i>	38.89	<i>Oscillatoria</i> <i>Symploca</i> <i>Chaetomorpha</i> <i>Enteromorpha</i> <i>Cladophora</i> <i>Polysiphonia</i> <i>Spirogyra</i>	0.56	<i>Protococcus</i> <i>Polysiphonia</i>
Diatoms	6.29	<i>Cyclotella</i> <i>Synedra</i> <i>Gyrosigma</i> <i>Pleurosigma</i> <i>Diploneis</i> <i>Navicula</i> <i>Nitzschia</i>	5.56	<i>Mastogloia</i> <i>Gyrosigma</i> <i>Pleurosigma</i> <i>Diploneis</i> <i>Navicula</i>	5.89	<i>Coscinodiscus</i> <i>Mastogloia</i> <i>Navicula</i> <i>Cymbella</i>
Miscellaneous matter ..	2.35	Copepod appendages. Copepods	24.44	Polychaete moults.	0.33	Polychaete moults.
Sand grains	17.47	..	5.22	..	6.00	..

TABLE VI

Prevalence (percentage) of Food Components of M. tade in the Estuarine Environment

	May	June	July	Aug.	Sept.	Oct.	Nov.
Decayed matter ..	100.0	97.0	100.0	84.8	100.0	88.8	88.9
Algae (Chlorophyceae and Myxophyceae) ..	..	75.8	100.0	78.7	21.4	77.8	11.1
Diatoms ..	100.0	84.8	100.0	87.8	21.4	33.3	77.8
Miscellaneous matter ..	100.0	30.3	28.0	9.1	30.0	40.0	11.1
Sand grains ..	100.0	93.9	100.0	90.9	78.6	77.8	77.8



TEXT-FIG. 4. Graphs showing the fluctuations in the volume of different items of food consumed during the various months in the estuarine environment. (a) Decayed organic matter represented by broken line, algae by continuous line and diatoms by dots and dashes. (b) Miscellaneous matter represented by continuous line and sand grains by broken line.

May, September and November are the peak periods of abundance of this item in the gut contents. In May it constituted 85% of the food consumed, and in September and November, about 64% and 87% respectively. It is of interest to note that during these months the algal component was very low. In August and October it occurred only in moderate quantities.

Algae (Chlorophyceae and Myxophyceae).—As in the sea, *Oscillatoria* spp. formed a very predominant algal component of the fish food in the estuary. It was seen that in August it constituted the major portion of the algal food. Other common algae in the gut contents were *Gloecapsa*, *Phormidium*, *Lyngbya*, *Chaetomorpha*, *Enteromorpha*, *Symploca*, *Microcoleus*, *Nostoc*, *Anabaena*, *Protococcus* and *Cosmarium*. Algal and fungal spores were also noticed in the gut contents. August and October were the months of abundance of algal food. In November it constituted less than 1% while in May it was absent in the guts.

Diatoms.—Relatively fewer diatoms were found in the guts of fish in the estuaries, due probably to the relative scarcity of diatoms in these areas. *Synedra*, *Gyrosigma*, *Pleurosigma*, and *Navicula* were the most common diatoms occurring in the gut contents. Other forms present were *Cyclotella*, *Coscinodiscus*, *Rhizosolenia*, *Tabel-laria*, *Fragilaria*, *Thalassiothrix*, *Asterionella*, *Mastogloia*, *Diploneis*, *Pinnularia*, *Tracheneis*, *Amphora*, *Cymbella*, *Nitzschia* and *Surirella*. In June and August the diatoms found in the guts formed 13.15% and 13.7% respectively of the food consumed. During other months they were less abundant, being less than 8.3% of the volume of the gut contents. *Navicula* was abundant in August and *Nitzschia* in June.

Miscellaneous matter.—The identifiable miscellaneous items in the gut of the fish in the estuaries were copepod and cladoceran appendages, polychaete moults, and nauplius and zoea larvae. Of these, polychaete moults formed the most predominant item. During the periods of scarcity of algae and diatoms, large quantities of these moults were seen in the stomach. The maximum quantity of miscellaneous matter, seen in October, formed more than 24% of the total gut contents.

Sand grains.—About 14% of the total gut contents of the fish consisted of fine sand grains. The largest quantity was met with in the month of August (26.7%) and moderate quantities in June, July and September (17.7%, 13.5% and 17.47% respectively). The minimum amounts occurred in October (5.22%) and November (6%).

3. Brackishwater Farm

Hora and Nair (1944) have described in detail a typical mullet farm (Bhasabadha fishery) in Bengal from the Sunderban area. The mullet farms of the Salt Lake Area near Calcutta, though generally similar to the typical Bhasabadha fisheries, are slightly different in layout and management. Because of the rapid silting up of the river system which feeds the farms, the force of tidal current has so diminished that enough water does not reach the farms. Tidal water is taken in for 2 or 3 days about the time of the full and new moons. The salinity of the water is reduced considerably during the rains. The fishes usually live in the canals adjoining the embankments or in the deeper areas of the farm, and only when the farm gets flooded with tidal or rain water do they move to shallow regions. At other times the major portion of the farm bottom lies exposed, overgrown with grass and plants like *Suaeda maritima*. When submerged, these plants decay and provide much needed organic manure for the growth of algae and diatoms. The fish farmers do not manure the farm, or take steps to increase the supply of food for the fish.

One hundred and sixteen specimens ranging from 64 mm. to 322 mm. caught in the evening or night in the months, February to October, were examined in detail. The samples collected during February, March and April were, however,

obtained in the mornings. Out of this collection, 60 were females and 44 were males, the remaining 12 being too immature to distinguish the sex. Sexually mature specimens have not so far been obtained from the farm. When the fish are about a foot in length they are caught and marketed, so that few of them have the chance to grow to maturity. Specimens more advanced than the III stage of maturity could not be obtained for study. Table VII shows the condition of feed of samples examined. An examination of the table reveals increased feeding activity from February to June, and again in October.

The quantitative and the qualitative analyses of the data are presented in Table VIII, the prevalence of different items in Table IX and Text-fig. 2, and the monthly fluctuations in Text-figs. 5a and 5b. These show that filamentous algae formed the major portion of the food of the fish in the farm. On an average it constituted 43.4% of the total gut contents. The next important item of food was decayed organic matter which formed 34.6% of the food consumed. Diatoms were a relatively less important item, forming only 9.5% of the contents. Miscellaneous items of food were rarely met with, and constituted only 0.7%. Sand grains formed 11.8% of the gut contents.

Decayed Organic matter.—During the months of heavy rainfall in the locality, namely, June, July and August, there was an abundance of decayed matter, forming 52.6%, 42.6% and 61.3% respectively, of the total gut contents. The period when minimum quantity was eaten was October, the next in order being April when it constituted 15% of the food consumed. Moderate quantities were eaten in February, March and May (30%, 31.25% and 34.6% respectively).

Algae (Chlorophyceae and Myxophyceae).—The abundance of algae, especially *Myxophyceae*, either floating, or forming a thick deposit at the bottom of the *bheris* has already been pointed out by Biswas (1927). Thick bluish green or blue black layers of fresh or decayed algae can often be seen adhering to grasses or other submerged plants along the margins of the farm. These algae appear to be a favourite item of mullet food in these farms as they predominate in the gut contents of specimens examined. Plate XXXIII, fig. 2, shows a sample of the gut contents of the fish from this locality.

TABLE VII

Statement showing the monthly frequency (in percentage) in the 'Condition of Feed' of samples examined from the Brackishwater Farm (Ghutiari Sharif)

Months	Frequency in percentage of specimens with stomachs :							
	Gorged	Full	$\frac{3}{4}$ full	$\frac{1}{2}$ full	$\frac{1}{4}$ full	With a little food	With very little food	Empty
February ..	..	87.5	12.5	..	..	..	..	..
March ..	25.0	25.0	50.0	..	..	..	..	..
April ..	..	100.0	..	..	..	..	..	..
May ..	50.0	50.0	..	..	..	..	..	..
June ..	25.0	50.0	..	25.0	..	..	..	..
July ..	20.0	..	..	..	20.0	20.0	40.0	..
August ..	11.1	..	5.6	11.1	33.3	11.1	11.1	16.7
September ..	..	..	..	..	..	..	..	100.0
October ..	75.0	..	..	..	..	..	25.0	..

The most predominant algae found in the gut contents were several species of the family *Oscillatoriaceae* which were abundant from June to August. Other

TABLE VIII

The qualitative and quantitative composition of the Gut contents of *M. tade* from the Brackishwater Farm

	February		March		April		May		June	
	%age	Food components	%age	Food components	%age	Food components	%age	Food components	%age	Food components
Decayed organic matter ..	30-00	..	31-25	..	15-00	..	34-60	..	52-60	..
Algae (Chlorophyceae and Myxophyceae).	42-30	<i>Oscillatoria</i> <i>Phormidium</i> <i>Microcoleis</i> <i>Anabaena</i> <i>Chaetomorpha</i> <i>Enteromorpha</i> <i>Polysiphonia</i> <i>Cosmarium</i>	47-25	<i>Oscillatoria</i> <i>Lyngbya</i> <i>Chaetomorpha</i> <i>Enteromorpha</i> <i>Polysiphonia</i>	42-50	<i>Oscillatoria</i> <i>Lyngbya</i> <i>Chaetomorpha</i> <i>Enteromorpha</i>	43-40	<i>Oscillatoria</i> <i>Lyngbya</i> <i>Chaetomorpha</i> <i>Polysiphonia</i>	34-00	<i>Oscillatoria</i> <i>Chaetomorpha</i> <i>Enteromorpha</i> <i>Polysiphonia</i> <i>Cosmarium</i>
Diatoms ..	8-10	<i>Coscinodiscus</i> <i>Eunotia</i> <i>Gyrosigma</i> <i>Pleurosigma</i> <i>Diploneis</i> <i>Navicula</i> <i>Cymbella</i> <i>Nitzschia</i>	6-00	<i>Gyrosigma</i>	32-50	<i>Gyrosigma</i>	9-50	<i>Gyrosigma</i> <i>Navicula</i>	4-80	<i>Skeletonema</i> <i>Synedra</i> <i>Pleurosigma</i> <i>Navicula</i> <i>Nitzschia</i>
Miscellaneous matter ..	0-80	Foraminifera Copepod ap- pendages Copepods.	0-50	Copepods Larval valves.	0-50	Copepods	0-70	Copepod ap- pendages.	0-10	Foraminifera Copepod re- mains.
Sand grains ..	18-80	..	15-00	..	9-50	..	11-80	..	8-50	..

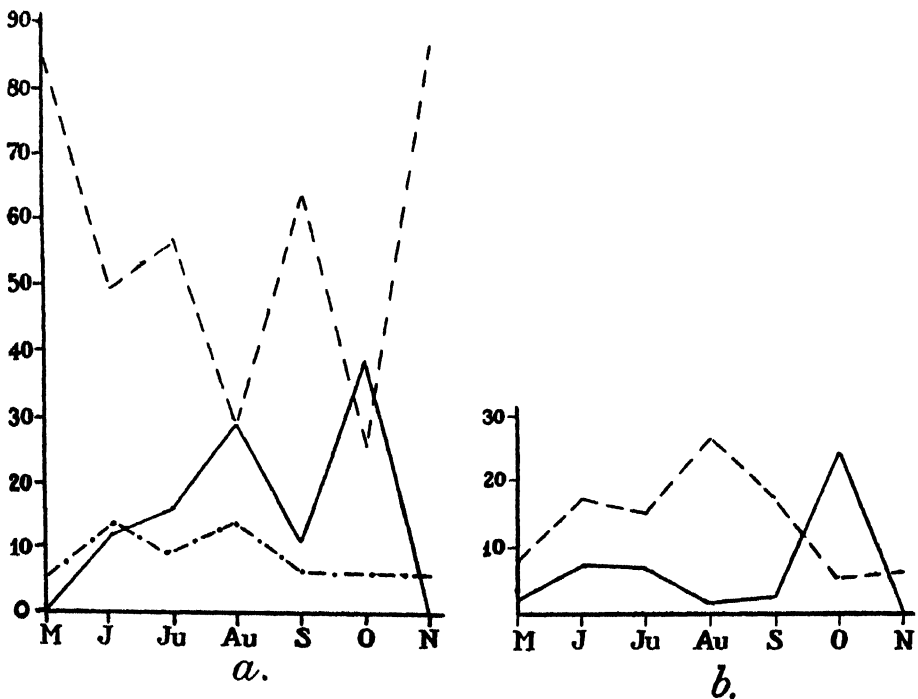
TABLE VIII (Contd.)
The qualitative and quantitative composition of the Gut contents of *M. tade* from the Brackishwater Farm

	July		August		September		October	
	%age.	Food components	%age.	Food components	%age.	Food components	%age.	Food components
Decayed matter ..	42.60	..	51.30	..	..	..	9.50	..
Algae (Chlorophyceae and Myxophyceae).	33.00	<i>Gloeocapsa</i> <i>Oscillatoria</i> <i>Polysiphonia</i>	16.50	<i>Gloeocapsa</i> <i>Oscillatoria</i> <i>Symploca</i> <i>Microcoleus</i> <i>Nostoc</i> <i>Anabaena</i> <i>Protococcus</i> <i>Chaetomorpha</i> <i>Enteromorpha</i> <i>Bulbochaete</i> <i>Polysiphonia</i> <i>Cosmarium</i>	..	..	88.00	<i>Oscillatoria</i> <i>Lyngbya</i> , <i>Protonococcus</i> <i>Spirogyra</i>
Diatoms ..	1.60	<i>Coscinodiscus</i> <i>Pleurosigma</i> <i>Navicula</i> <i>Nitzschia</i>	11.10	<i>Melosira</i> <i>Cyclotella</i> <i>Coscinodiscus</i> <i>Tabellaria</i> <i>Synedra</i> <i>Mastogloia</i> <i>Thalassiothrix</i> <i>Gyrodinium</i> <i>Pleurosigma</i> <i>Diploneis</i> <i>Navicula</i> <i>Pinnularia</i>	..	..	2.50	<i>Diploneis</i>
Miscellaneous matter ..	2.00	Copepod remains. Polychaete moults.	1.30	Copepods Polychaete moults.	..	..	..	..
Sand grains ..	20.80	..	9.80	..	..	..	..	..

TABLE IX

Prevalence (percentage) of Food Components of *M. tade* in the Brackishwater Farm

	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.
Decayed matter ..	100.0	100.0	100.0	89.3	100.0	100.0	100.0	..	25.0
Algae (Chlorophyceae and Myxophyceae).	100.0	100.0	96.2	100.0	100.0	80.0	93.3	..	100.0
Diatoms ..	100.0	100.0	100.0	80.7	80.0	80.0	80.0	..	25.0
Miscellaneous matter	50.0	50.0	37.6	50.0	20.0	40.0	53.3	..	..
Sand grains ..	87.5	100.0	100.0	100.0	77.3	100.0	53.3	..	..



TEXT-FIG. 5. Graphs showing the fluctuations in the volume of different items of food consumed in the brackishwater farm. (a) Decayed organic matter represented by broken line, algae by continuous line and diatoms by dots and dashes. (b) Miscellaneous matter represented by continuous line and sand grains by broken line.

common algae were *Gloecapsa*, *Phormidium*, *Lyngbya*, *Symploca*, *Microcoleus*, *Nostoc*, *Anabaena*, *Protococcus*, *Chaetomorpha*, *Enteromorpha*, *Bulbochaete*, *Polysiphonia*, *Cosmarium* and *Spirogyra*. A thick slimy brownish mass consisting of different species of *Spirogyra*, *Oscillatoria* and *Lyngbya* formed invariably the gut contents of the fish examined in the month of October. *Polysiphonia* was very common in February, and *Enteromorpha* in March. It is of interest to note that *Euglena* sp., *Pandorina morum* and *Arthrospira platensis* which are usually found in association in the form of a thin yellowish green surface scum (*vide* Biswas, 1927) has not been met with in the gut contents of the fish. This lends further support to the view that the fish does not generally feed at the surface.

Almost throughout the year fairly large quantities of algae occurred in the gut of the fish, more particularly in October when they formed about 88% of the total food consumed. From February to May the algal component ranged between 42.3% and 47.25%; while it was 34% and 33% respectively in June and July and 16.5% in August. In September the gut in all the specimens examined were empty.

Diatoms.—Diatoms do not form a major item of food of fish in the farm as in the estuaries. Most of them found in the gut are forms commonly attached to filamentous algal, *Gyrosigma scalproides* being the commonest among the species. In February, March and April the major portion of the diatoms eaten was of this genus. The other important diatoms identified were *Melosira*, *Skeletonema*, *Cyclotella*, *Coscinodiscus*, *Tabellaria*, *Synedra*, *Mastogloia*, *Thalassiothrix*, *Eunotia*, *Pleurosigma*, *Diploneis*, *Navicula*, *Pinnularia*, *Cymbella*, *Bucillaria*, *Nitzschia* and *Surirella*.

The largest quantities of diatoms were found in the guts during the month of April, when they formed 32.5% of the total food. In February (8.1%), March (6%), May (9.5%) and June (4.8%) small quantities were consumed while in July and October they were scarce, being only 1.6% and 2.5% respectively of the total food eaten. In August the percentage was higher, being 11.1%.

Miscellaneous matter.—Copepod and cladoceran appendages, polychaete moults and foraminiferan shells were the identifiable miscellaneous matter found in the gut contents. The percentage of such items was, however, less than 1% in all but the months of July and August, when it was higher (2.0% and 1.3% respectively). In October, when the algal food was abundant, miscellaneous items were not found in the stomach of the fish.

Sand grains.—Fine sand grains occurred in the gut throughout the period of investigation except in October. In February, March and July the percentages of sand grains were relatively high (18.8%, 15% and 20.8% respectively) as compared to April and May (9.5% and 11.8% respectively). In October the abundance of algal food in the guts was correlated with the abundance of growth of algae on the bottom and marginal areas of the farm. Naturally, with such abundance of food in October, the fish had no need to scrape or swallow mud to obtain its quota of algal food, and hence the complete absence of sand grains in the gut during the month.

4. *Freshwater Tanks*

Grey mullets are cultured in freshwater tanks in the coastal areas of Contai district (*vide* Pillay, 1949). For the purpose of this investigation specimens were obtained from such tanks in Junput (Contai). There was considerable difficulty in obtaining enough number of specimens as fishing is done only occasionally, and the number of *M. tade* in the tanks is not high. Sixty-eight specimens ranging from 89 mm. to 330 mm. in length were examined during April. Out of these 16 were males, 24 were females and the rest were too immature to ascertain the sex. None of the specimens were more advanced than the II stage in maturity. About 8.3% of the specimens had 'gorged' and, 25.1% had 'full' stomachs. 8.3% had '¾ full' and an equal percentage were in '¼ full' condition of feed, while 50% had only a little food in the stomach. A few specimens were obtained during other months also, but the number being too small, the data are not discussed here.

Table X presents the qualitative and quantitative analyses of the gut contents from this type of environment. This shows that algae formed the most predominant type of food consumed and constituted 54% of the total food, the next in importance being decayed organic matter which formed 19.17%. The percentage of diatoms was as low as 1.83%. As it was not possible to obtain sufficient number of specimens from freshwater tanks during different months, the present analysis gives only a rough picture of the food of the fish in freshwater tanks.

TABLE X

Qualitative and quantitative composition of the Gut contents of Mugil tade Forsk. from Freshwater tanks

	Percentage by volume	Food components.
Decayed organic matter	19.17	....
Algae (Chlorophyceae and Myxophyceae) ..	54.00	<i>Ankistrodesmus</i> <i>Chlorella</i> <i>Closterium</i> <i>Coelastrum</i> <i>Cosmarium</i> <i>Oscillatoria</i> <i>Nostoc</i> <i>Anabaena</i>
Diatoms	1.83	<i>Navicula</i> <i>Surirella</i> <i>Cymbella</i> <i>Cyclotella</i>
Miscellaneous matter	14.17	<i>Daphnia</i> Copepod appendages
Sand Grains	10.83	.. .

Oscillatoria, *Nostoc*, *Anabaena* and *Spirogyra* were the predominant algal constituents in the gut contents. The other important algae identified were *Clathrocystis*, *Gloecapsa*, *Phormidium*, *Protococcus*, *Nostochopsis*, *Cosmarium*, *Chlorella* and *Tribonema*. The chief diatoms identified from the gut contents were *Pleurosigma*, *Diploneis*, *Navicula* and *Surirella*. Some of the fish examined from the tanks had Daphnids in the stomachs, both entire specimens as well as their appendages. Copepod appendages formed the other item of this category.

5. Food of juveniles and change in the composition of food with growth

Among the localities investigated, only in the marine environment were all size groups, especially the early ones, available for study in sufficient numbers. So the data obtained from this area was further analysed to elucidate the food of juveniles and their change to adult feeding. The fish collected were mainly from creeks and tidal springs in the months of June, July and August. Ninety specimens, ranging from 15 mm. to 140 mm. in total length were grouped into 20 mm. groups and the volumetric composition of the food of each group studied is given in Table XI. The prevalence of each item of food in the different groups is represented in Text-fig. 6.

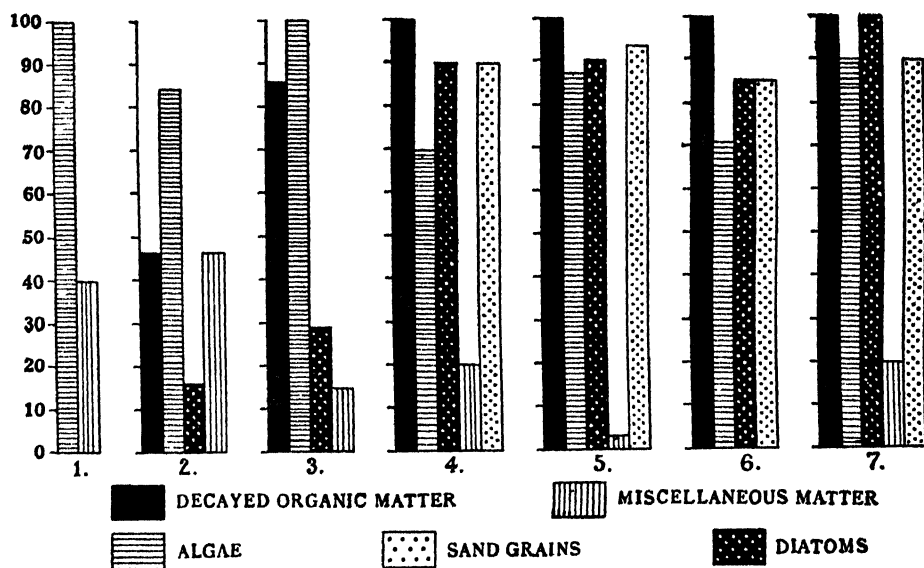
The analysis reveals the striking fact that the food of the early juveniles (up to 20 mm. in total length) consists mainly of algae mixed with a little quantity of miscellaneous matter. All the specimens examined had algae in the stomach and 40% of them had consumed miscellaneous matter. The algae consumed consisted mainly of Myxophyceae. The complete absence of sand grains indicates that they feed either at the surface zones or on attached and floating algae in the littoral regions.

The next group (21 mm. to 40 mm.) begins to feed on decayed organic matter as evidenced by the fact that 46.2% of the guts examined contained this item.

TABLE XI

Volumetric composition of the food of different size groups of Mugil tade

Length Group	0-20 mm.	21-40 mm.	41-60 mm.	61-80 mm.	81-100 mm.	101-120 mm.	121-140 mm.
Decayed matter ..	..	19.1%	41.4%	33.7%	36.7%	55.7%	30.0%
Algae (Chlorophyceae and Myxophyceae) ..	95.0%	57.9%	54.0%	15.9%	9.8%	11.0%	9.5%
Diatoms ..	..	0.3%	3.9%	31.0%	40.7%	19.0%	39.0%
Miscellaneous matter ..	5.0%	22.7%	0.7%	5.1%	0.2%	..	7.8%
Sand Grains ..	..	..	..	14.3%	12.6%	14.3%	13.7%



TEXT-FIG. 6. Histograms showing the prevalence, in percentage, of food constituents analysed according to size groups. (1) 0-20 mm., (2) 21-40 mm., (3) 41-60 mm., (4) 61-80 mm., (5) 81-100 mm., (6) 101-120 mm., (7) 121-140 mm.

But the quantity eaten was insignificant. An equal percentage of guts examined contained miscellaneous matter (consisting of mysids, copepods and cladocerans) constituting 22.7% of the bulk of the food eaten. This was observed to be the stage when the largest quantity of animalcules was eaten. Algae, however, formed the most predominant item of food even at this stage. Sand grains were completely absent in the gut contents.

The main features of the food of the next group (41-60 mm.) is that the volume of decayed matter has increased considerably and that there is a marked decrease in the quantity as well as prevalence of miscellaneous matter in the diet. There is also a slight increase in the quantity of diatoms eaten.

The data show that the change over to adult feeding starts during the next stage, *viz.*, 61-80 mm., when sand grains appear in the stomach for the first time. All the guts examined had decayed organic matter, 70% had algae, 90% had both diatoms and sand grains and 20% had miscellaneous matter. This observation is supported by the fact that the pharyngeal apparatus for sieving mud is fully

developed in the fish only at this stage (*vide infra*, p. 811). It will be noticed from Table XI and Text-fig. 6, that from this stage onwards all the fish examined had decayed matter and a large majority had algae, diatoms and sand grains in the guts. Miscellaneous matter occurred in the food only rarely and was mainly composed of polychaete moults and crustacean appendages that would probably have been consumed from the benthic zones along with other food materials.

(v) Observations on feeding habits

From the food habits of the fish discussed above, it will be clear that the adult mullet is an iliophage.* The fact that the guts of specimens examined invariably contained mud mixed with algal matter clearly shows that the zone of feeding is not the surface or the mid-water. Regular plankton studies and simultaneous examination of gut contents of fish conducted during the initial stages of this investigation proved that planktonic organisms are not generally found in the gut contents. The few surface diatoms that were occasionally found in the guts do not serve to disprove the bottom feeding habit, as these diatoms are known to settle down to the bottom. The fish possesses an inferior mouth and a dorso-ventrally compressed conical head, a shape admirably suited for feeding at the bottom or in littoral areas. Like *M. corsula*, *M. tade* has also a prominent symphysial knob fitting into a corresponding notch in the upper jaw, which according to Hora (1938) helps the fish in nibbling on attached algae.

The enclosed farms and the muddy littoral areas of the sea are the most suitable localities for observing the feeding habits of mullets under natural conditions. The best time to observe them feed in the sea is when the tide rises. With the tide the fish also ascend in shoals to the littoral areas, and below the tidal waves they can be seen sucking in food from the thick iliophobic layer found in this region. The body of the fish, while feeding, is inclined at about 30°–40° to the substratum. In very shallow areas, the caudal fin can be seen lashing above the surface of the water. One is often reminded of a herd of cattle grazing on a rich pasture, when the shoal advances on to the beach feeding avidly on the muddy bottom. The shoals often consist of *M. corsula* and *M. persia* also. The fishermen report that a large shoal thus feeding, produces a loud smacking sound which they take as the signal to operate their nets.

The fish farmers are of the opinion that the early morning and evening hours are the feeding times of the fish and they therefore usually prefer to operate their nets for mullets at such hours. I have however not been able to corroborate this, as I have obtained specimens gorged with food at all hours of the day.

When a shoal of mullets are found to feed thus, on the sea coast of Contai (Junput, Midnapore Dist.), the fishermen quickly encircle it with a hand-seine (*Katti-jal*). The net is then dragged ashore, and if skilfully operated, the catches are usually considerable. In the Sunderbans also the fishermen locate the presence of mullet schools at high tide, by the sucking noise produced while feeding.

It is an engaging sight to see the schools of fry feed. Anchored boats and submerged pieces of wood or other hard objects are usually coated with a thick covering of algal matrix consisting of blue-green and green algae. The fry gather round these objects and pluck out the algae, often leaving the surface quite clean.

The *bheris* of Sunderbans generally have swampy areas adjoining them. The fish farmers there reported to me during one of my visits that *M. tade* bite and feed on the bark of the Mangrove, *Avicennia officinalis*. Examination of the submerged parts of this plant showed profuse growths of the alga *Protococcus viridis*. Later I had opportunities of actually observing them feed on these algal growths.

* An animal which obtains food from the mud, consisting of benthic plant and animal life together with organic particles, which form a layer known as the iliophobic layer on the muddy bottom of water areas (Morris, 1936; Allen, 1936; and Fox and Amstein, 1936).

The feeding activity of the fry of *M. tade* was observed in aquaria, into which were introduced pieces of wood and stones having thick growths of algae on them. The fish could be seen readily plucking out the slimy algae, more particularly the soft decaying filaments. As between submerged algal growths and iliotrophic layers placed on purpose within their reach, the fish seldom preferred the latter. But in the absence of such food they nose about in the mud, sucking in the decayed matter or accumulations of algae. Plankton collected from the estuarine areas was introduced into the aquaria, but the fish were not found to feed on them in the presence of its natural food. The feeding of starved mullets in aquaria is interesting. They peck at almost anything that come their way, with the result that the copepods, cladocerans, worms, etc. pecked by them die and settle down at the bottom, untouched by the fish again. Microplanktonic organisms were, however, detected in the stomach of the fish later.

Gadsen (1899) stated that 'the mullet is almost, if not quite, the most difficult fish to get on even terms with'. After many years' experience, he came to the conclusion that 'there is but one bait which is worth trying, and to which he will generally succumb, a very simple bait, and one easily obtained and as easily applied, viz., the lightbrown crust of a loaf of bread'. Bickerdye (1943) recommended ground baiting to catch mullets. These observations indicate the bottom feeding habits of the fish. Bickerdye also noticed the typical habit of mullet trying to reject the hook as soon as it feels it in the bait. The Adyar fishermen use lumps of slimy algae as bait for catching mullets on hook and line (Sarojini, *op. cit.*). This practice is based on the herbivorous habits of the fish.

III. MORPHOLOGY AND HISTOLOGY OF THE ALIMENTARY TRACT AND ITS GLANDS

(i) *Historical résumé*

Günther (1861 and 1880) referred to the striking characters of the alimentary tract of mullets of which the peculiar pharyngeal apparatus forms a part. Goodrich (1909) mentioned long internal papillae in the oesophagus of *Mugil*. Jacot (1920) described the development of the convolutions of the intestine in *Mugil cephalus*. Ghazzawi (1935) made a somewhat detailed study of the gross anatomy and histology of the pharynx and intestinal tract of an Egyptian mullet (*M. capito*), but without reference to the structure of the mouth, or the process of deglutition, or even the glands such as liver and pancreas connected with the alimentary tract. Ishida (1935) found no gastric glands in *M. cephalus*, and neither proteolytic nor lipolytic enzymes in its stomach, a condition associated with herbivorous habits. It may be pointed out that Ghazzawi (*op. cit.*) described gastric glands in the stomach of *M. capito*. Rahimulla (1945 and 1947-48) noted the number and arrangement of pyloric caeca in *M. cephalus* and *M. speigleri*, and reported (1948) having worked out the morphological details of the alimentary canal in general and pyloric caeca in particular, of *M. troscheli*, but the results have not been published so far. From the above résumé it will be clear that no complete study of the alimentary tract and its appendages with reference to the food and feeding habits of any mullet has been done so far.

(ii) *Material and Methods*

The material for the present study was collected mainly from the three types of localities from where specimens were obtained for the study of the food and feeding habits, viz., the sea (Junput, Midnapore Dist.), the estuary (Port Canning on the Matla river) and the brackishwater farm at Ghutiar Sharif (24-Parganas).

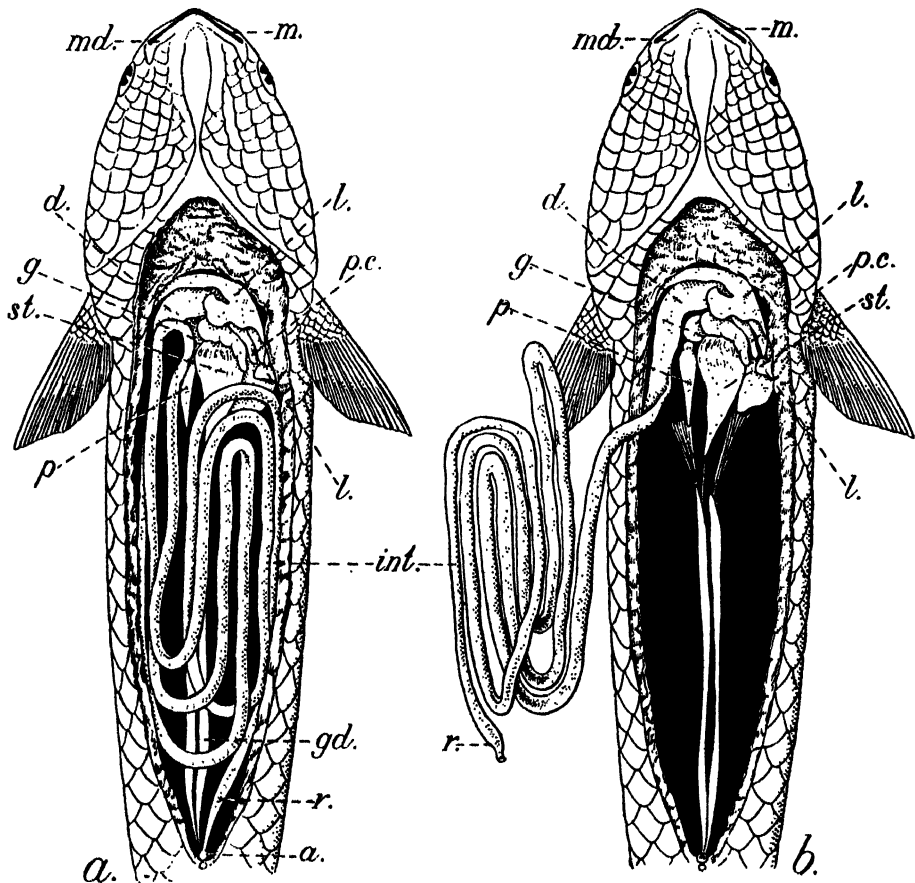
Fresh specimens were used for dissection and for the study of variations. To study the mechanism of the protrusible mouth, the head skeleton was prepared

by dipping the heads of fresh specimens for a short time in boiling water and gently removing the flesh by means of a scalpel. The bones were finally cleaned in caustic potash solution. Alizarin preparations of the heads were also made. The process of deglutition was studied by direct observation in aquaria and by observing the movements of muscles, previously exposed by dissection, when the mouth is opened and closed artificially.

For histological studies, the material was fixed in Bouins fluid or 5% formalin and sections were cut 5–9 μ in thickness. Delafield's and Ehrlich's haematoxylin, Heidenhain's iron alum haematoxylin and Mallory's triple were used for staining the sections.

(iii) *Morphology of the alimentary tract*

The alimentary tract of *Mugil tade* is an extremely coiled organ (Text-fig. 7a). It lies below the air bladder which extends throughout the coelomic cavity. The



TEXT-FIG. 7. (a) Ventral view of the viscera *in situ*.

(b) Ventral view with the alimentary tract uncoiled.

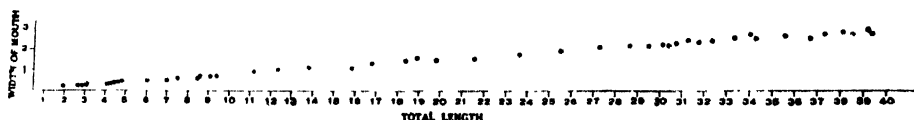
m.—Mouth
l.—Liver
g.—Gall bladder
gd.—Gonad
p.c.—Pyloric caeca
int.—Intestine

a.—Anus.
md.—Mandible
d.—Duodenum
st.—Stomach
p.—Pancreas
r.—Rectum

following regions can be distinguished in the alimentary tract: the mouth, the stomach, the intestine and the rectum. The mouth, buccal cavity, pharynx, oesophagus and stomach can be easily recognised, but the exact boundaries of the other regions are not clearly marked out. The duodenal region can, however, be distinguished by its thickness, and the intestine and the rectum by the nature of their internal lining.

1. Mouth

The V-shaped mouth is slightly inferior in position in full grown specimens, with the angle between the limbs of the V about 120° . It may be classed under the 'normal type' of mouth (Gregory, 1933). The gape is moderate, contained about 10 to 15 times in the length of the fish and about 2.7 to 3.4 times in the length of the head. In Text-fig. 8 the width of the mouth is plotted against the total length of the fish. The graph shows that the relationship between the length of the fish and the width of its mouth is constant, the coefficient of correlation, r , being 0.925 ($P = \pm 0.1$). The upper lip bears numerous truncated minute teeth (Text-fig. 10a), which are absent in the lower, their place being taken by papillary thickenings.

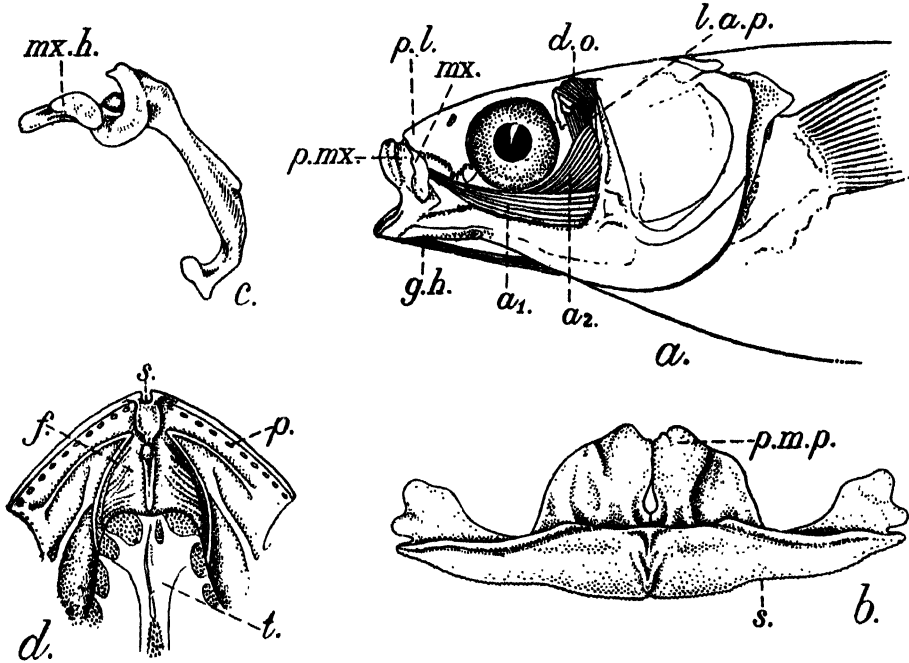


TEXT-FIG. 8. Scatter diagram showing the relationship between the width of the mouth and the total length of the fish.

The mouth is moderately protractile even though the protrusibility and related adaptations are not so marked as in fishes like *Epibulus insidiator* or *Equula dussumieri* (Delsman, 1925). Eaton (1935) has commented on the striking resemblance between the upper jaw mechanisms of *Fundulus* and *Mugil*. In *M. tade*, the maxillae are excluded from the gape of the mouth. If the thin lower jaw is pulled down, the thick upper jaw gets drawn forwards, and the mouth opening becomes inferior in position. The two premaxillae that bound the upper half of the mouth are united and have very fine serrations on them. Each premaxilla has a flattened dorsal process (Text-fig. 9b). The dorsal processes of the two premaxillae are united edge to edge, except for a little portion at the middle region. These processes together form a semi-circular projection in the middle region of the premaxillary with a deep notch dorsally. This gap is covered by an unpaired piece of cartilage. This premaxillary process can be termed the 'sliding stalk' on which the protractile mechanism works (Delsman, *op. cit.*). The premaxillaries are attached to the lateral ethmoids by the rostral ligaments. The maxillae are slender and bow-like (Text-fig. 9c). At the upper end of each maxilla there is a deep hook-like structure, with its lower arch fitting into a corresponding shallow socket on the surface of the premaxillary process.

The working of the protractile apparatus is mainly governed by the action of the adductor mandibulae (Text-fig. 9a). The lower external part of each muscle (A1) is somewhat smaller, and originates along the lower edges of the preopercle and the quadrate. The external part of the adductor (A2) begins on the symplectic and the hyomandibular, and is attached to the coronoid angle of the mandible. The internal part of the muscle (A3) originates from the face of the metapterygoid and is inserted on the tendonous fascia of the inner face of A2. The intra-mandibular portion (A) is very small, and connects A2 and A3. The second of the two separate levator-arcus-palatini forms a thin sheet under the eye-ball.

The lower ends of the maxillae are attached to the mandible behind the angle of the mouth by means of ligaments. The upper lip is fairly thick, its thickness being contained 3.0 to 3.6 times in the orbit. It is fringed with minute teeth (Text-fig. 10a) having simple truncate tips. In the lower jaw the dentaries are held together at the symphysis by a very short ligament which allows only slight movement. The symphysis has a single prominent knob, which fits into a corresponding notch on the premaxillary. The lower lip has a thin, straight edge.



TEXT-FIG. 9. (a) Dissection showing the protrusible mouth.

p.mx.—Premaxilla

mx.—Maxilla

l.a.p.—Lateral arois palatini

a₁—Arcus palatini—1

(b) The premaxillae.

p.m.p.—Premaxillary process

(c) Maxilla.

mx.h.—Maxillary hook.

(d) The floor of the mouth.

s.—Symphysis

f.—Folds

p.l.—Palatine

d.o.—Dilator operculi

g.h.—Geneohyoidei

a₂—Arcus palatini—2

s.—Serrations

p.—Papilla

t.—Tongue.

Deglutition.—The lower jaw is opened to admit food mainly by the action of the geneohyoidei and the sternohyoidei (Text-fig. 9a). When the mouth is opened, the lower jaw pulling forward the maxillae and the adductor muscles at the same time retarding the movement, the maxillae get twisted on their own axes. The curved shafts of the maxillae facilitate this twisting action. The internal limbs of the maxillary hooks thrust against the premaxillary processes sliding them forward. Thus when the mouth is protruded the gape is ventral in position. The mouth engulfs the food particles entire, by a quick snap, probably exerting a sucking force. The symphyseal knob is probably helpful to the fish in plucking out attached algae

(Hora, 1938). After the food has been taken in, the mouth is closed by the action of the adductor mandibulae. A backward twist of the maxillaries draws the upper jaw back.

Though in juveniles also the process of deglutition is similar, the mouth does not become distinctly inferior, but is almost anterior in position. This fact finds correlation with the surface feeding habits of the juveniles.

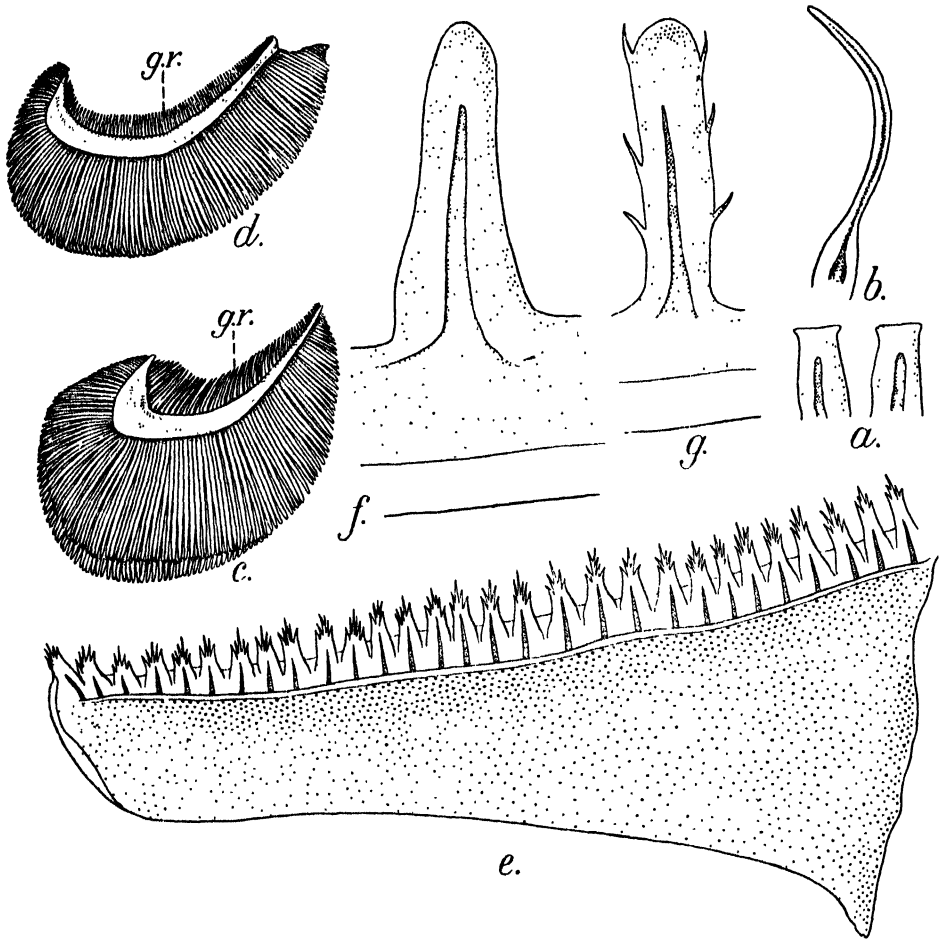
2. *Buccal cavity*

The mouth leads into the triangular dorso-ventrally compressed buccal cavity (Text-fig. 9d), its length in a specimen 363 mm. long being 40 mm. The roof of the buccal cavity supported by the cranium and lined by a thick fine-ridged membrane, has a groove along its middle, into which the anterior sharp ridge formed by the basibranchials fits. These ridges are clearly longitudinal on the palate. Moderately thick muscles support the floor of the cavity. A rudimentary tongue represented by a thick elevated area of mucous membrane provided with free lateral edges and a forwardly projecting apex, is present on the floor of the mouth, supported by the basihyal element of the hyoid arch. The thick, ridged lining of the floor of the mouth is well adapted for the type of food the mullet consumes.

3. *Pharynx*

The buccal cavity leads into the broader dorso-ventrally compressed pharynx, the roof of which is supported by the base of the cranium and the floor by the median basibranchial and hypobranchial elements of the branchial arches. The sides are bounded by the cerato and epihyal elements. The pharyngeal cavity is 33 mm. long in a 363 mm. long specimen. The most remarkable feature of the pharynx region is the so-called pharyngeal apparatus which almost completely occupies it. The roof of the pharyngeal cavity has a pair of pharyngeal cushions supported by the upper pharyngeal bones with a deep groove between the cushions (Plate XXXIII, Fig. 5). There is a medial raised portion on each cushion, with about eight transverse grooves on it. The surface of the cushion is covered with innumerable densely-packed seta-like teeth which are minute, broad-based and enamel-covered (Text-fig. 10b) with pulp cavity extending from the base to the crown. The teeth project from the underlying tissue of the cushion in which are embedded numerous teeth in different stages of development in between the functional ones, which are evidently meant to replace the worn-out functional teeth. Thus *M. tade* exhibits polyphyodont condition, as old teeth are replaced by new ones, presumably several times during the life of the fish.

The pharyngeal cavity is perforated by the gill slits which are in communication with the branchial chamber. There are four pairs of gills, each with two rows of gill rakers which serve to protect the gill opening. The rakers of the anterior row on each gill arch are longest in the middle of the arch, shortening towards each end. The rakers of the posterior row, are all nearly of the same length. The rakers of the anterior row of the first gill arch (anterior-most) (Text-fig. 10c) are the longest, and in a 220 mm. specimen the longest rakers are about 5 mm. in length. Those of the posterior row are shorter with a maximum length of 2 mm. In the second and third gill arches (Text-fig. 10d) also the anterior rakers are longer than the posterior ones; but the difference in length is not so marked as in the rakers of the first arch. In the specimen mentioned above (220 mm. long) the maximum lengths of the rakers of the anterior and posterior rows of these arches were 3 mm. and 2 mm. respectively. The fourth or the last gill arch has only a single row of gill rakers located on its inner anterior edge and almost as long as the anterior rakers of the second and third gill arches. Besides these, there is one row of rakers on the pharyngeal behind the last gill slit of each side.



TEXT-FIG. 10. (a) Oral teeth
 (b) Pharyngeal teeth
 (c) First gill g.r.—Gill raker
 (d) Second gill g.r.—Gill raker
 (e) A gill raker showing the seta-like processes
 (f) The process of the gill raker of a 15 mm. long fish
 (g) The process of the gill raker of 47 mm. long fish.

The anterior-most row of gill rakers is the longest as it guards the relatively large passage between the first gill and the opercle. Each gill raker has two rows of processes on it, of which those of the first arch are smooth, and of the others have tuft-like growths of long pointed bristles (Text-fig. 10e). These tufts of bristles interlock with the similar structures of the adjacent arch thus forming a very efficient sieving apparatus on each side of the pharyngeal cavity (Plate XXXIII, Fig. 4).

Sieving of Food Materials.—*M. tade* feeds mainly on decayed organic matter, algae and diatoms, found on the muddy bottom of the sea, estuary or enclosed waters. Along with these food materials, considerable quantities of coarse indigestible matter such as sand particles and undecayed parts of macroflora are also gulped in, but these are sieved out before the food enters the oesophagus. This is done by means of the pharyngeal cushions and the gill rakers. In the

herbivorous carp, *Labeo rohita*, the pharyngeal teeth are masticatory in function (Sarbah, *op. cit.*), but in *M. tade* the setiform teeth on the cushions form only a straining apparatus. The gill arches of each side with its gill rakers, work on the pharyngeal cushion of that side. According to Günther (1861) mullets take in mud which is worked for some time between the pharyngeal bones and the rough and indigestible portions of it are ejected. The coarser particles of sand and other objects are sieved through the pharyngeal apparatus to be thrown out.

Development of the Pharyngeal Apparatus.—The smallest specimens of *M. tade* available for study was 15 mm. long. In these the gill rakers and their processes are already developed; but the latter do not bear the bristle-like tufts, which appear as short prolongations in fish about 16.5 mm. long and are well developed in fish about 47 mm. long.

The pharyngeal cushions do not show any teeth on the surface in specimens 15 mm. long, though their presence in the tissue of the cushions is evident. In specimens 45 mm. long the teeth appear above the surface as very short bristles and in fish 62 mm. long they are fairly prominent. In specimens 93 mm. long the teeth are as prominent as in adults.

4. *Oesophagus*

The narrow deep groove (49 mm. long in a 363 mm. long specimen) between the two pharyngeal cushions leads into the anteriorly wide muscular oesophagus. The pneumatic duct leading to the air bladder is located on the antero-dorsal aspect of the oesophagus, which joins the stomach dorsally at the region just above its cardiac part (Text-fig. 7b), where it is broader.

The dorso-ventrally compressed region described by Ghazzawi (1935) in the oesophagus of *M. capito* could not be recognised in *M. tade*. The 7 or 8 prominent longitudinal muscular folds of the internal wall of the oesophagus, corresponding to the internal papillae described by Goodrich (*op. cit.*) are distinctly more prominent and muscular distally near the opening of the oesophagus into the stomach, and probably help, to some extent, in crushing the food matter.

The oesophagus conveys the strained food materials from the pharynx to the stomach.

5. *Stomach*

The stomach (Text-fig. 7b and Plate XXXIII, Fig. 6) consists of two regions: an anterior gizzard-like pyloric region or the pylorus, and a posterior conical cardiac region. The stomach is lined internally with longitudinal folds (Plate XXXIII, Fig. 6), a very prominent fold of which runs dorsally, with its maximum depth at the opening of the oesophagus into the stomach, acting as a valve.

Plate XXXIII, Fig. 3, shows the shape of the stomach when it has little food and when gorged with food. The variable length of the stomach is contained 8–10 times in the total length of the fish, but in gorged specimens it is only 3.4 times, and this remarkable increase in the length of the stomach is due to the expansion of the cardiac region. While normally its wall is thick and muscular, in the gorged and expanded condition it becomes extremely thin and transparent and the internal folds disappear. The disappearance or reduction of internal foldings of distended stomachs has been observed in *Salmo* by Greene (1913) and in Sea-robin by Blake (1936).

The roughly rhomboidal pylorus or the pyloric part of the stomach is exceedingly thick and muscular with a very narrow cylindrical lumen which, consequently (as seen in Plate XXXIII, Fig. 6), gives the wall of the pylorus its greatest thickness at the mid-point. The inner wall of the pyloric stomach also is thrown into longitudinal folds. The five pyloric caeca of which one is 1–3 times longer

than the others, are arranged in the form of a semi-whorl, each opening independently on the ventral side of the duodenum beyond the pylorus, as in *M. cephalus* (Rahimullah, 1947-48). They do not open into a common channel as observed by Ghazzawi (*op. cit.*) in *M. capito*.

The food of the mullet includes tough filamentous algae, and silicious diatoms. The organic matter sucked in from the mud when not fully decayed is coarse, and the mullet has no specialised masticatory apparatus. As the oral teeth are feeble the pharyngeal teeth subserve the function of filtration only. It is probably to compensate for the lack of a masticatory apparatus that the stomach of the mullet has the structure of a muscular gizzard, in which the hard food matter is comminuted and partly digested.

6. *Intestine*

The intestine starts from the anterior end of the pylorus, takes a loop and passes back above the right half of the stomach, forming a relatively thick duodenum. (Text-fig. 7a and 7b) the mucous membrane of which is thrown into very prominent folds.

Behind the duodenum the highly coiled intestine is of uniform diameter and with a thin wall (Text-fig. 7b). Starting from the duodenum it loops 8 times before passing on to the rectum. The mucous lining of the intestine is thrown into short papillary outgrowths.

Fish 16 mm. long have the simplest form of intestine, consisting of a duodenal loop and a 'straight-away' to the anus; and the coils are later developed in a similar manner as observed by Jacot (1920) in the case of *M. cephalus*.

7. *Rectum*

The rectum is short and slightly narrower than the intestine. In a fish 363 mm. long it was 55 mm. in length. It communicates with the exterior by means of the anal opening situated anterior to the genital opening. The mucosal lining of the rectum is raised into broad granular outgrowths which, in fresh specimens, are blood-red in colour.

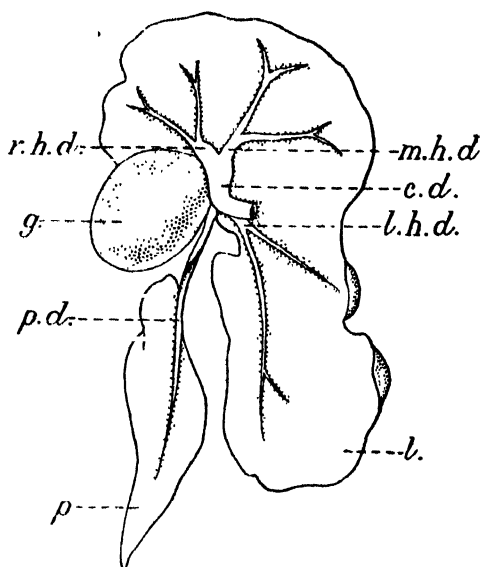
(iv) *Morphology of the Glands of the Alimentary Tract*

1. *Liver*

The yellowish liver covers the anterior portions of the stomach and the intestinal coils (Text-figs. 7a and 11). The main mass of the liver lying dorsal to the alimentary tract is produced posteriorly into two distinct unequal lobes, the longer left lobe being 50 mm. long and the shorter right lobe 24 mm. long in a fish 363 mm. long. The liver occupies only the anterior portion of the abdominal cavity and does not extend beyond one-third of its length. Each lobe has many irregular sub-lobes. The left lobe has shallow depressions into which the gizzard and a part of the intestinal coils fit in.

The gall bladder lies between the right lobe of the liver and the pyloric part of the stomach. It is thin walled, nearly spherical in shape, and 17 mm. in diameter in a specimen 363 mm. long.

The cystic duct is very short (7 mm. in a 363 mm. long fish) and broad. It starts from the antero-ventral aspect of the gall bladder receiving very near its origin, the right hepatic duct from the right hepatic lobe. A little posterior to the opening of the right hepatic duct, it is joined by the median hepatic duct from the median lobe. After the cystic duct has traversed a short distance posteriorly it receives the left hepatic duct from the left hepatic lobe. Of the three hepatic ducts, the right one is the shortest (Text-fig. 11) and the left the longest. Each of the



TEXT-FIG. 11. The glands connected with the alimentary tract.

- r.h.d.*—Right hepatic duct
- g.*—Gall bladder
- p.d.*—Pancreatic duct
- p.*—Pancreas
- m.h.d.*—Median hepatic duct
- c.d.*—Cystic duct
- l.*—Liver
- l.h.d.*—Left hepatic duct.

three has two branches, the branches of the right and the median ducts being short. One branch of the left hepatic duct is formed near the posterior end of the left hepatic lobe by the union of two short ducts. The other branch starts from about the middle of the lateral edge of the left hepatic lobe and runs obliquely to join the other branch a little before it opens into the cystic duct. The bile is yellowish green in colour.

2. *Pancreas*

There is a distinct pancreas in *M. tade* which, in many other fishes, may be wholly or partly diffuse, the diffuse mass being scattered more or less all over the visceral cavity (Hill, 1926). It is purple red in colour, and broad anteriorly and tapering to a point posteriorly. In a specimen 363 mm. long the pancreas is 46 mm. long. The long and narrow pancreatic duct which starts dorsally from near its posterior end and runs forward along its right lateral edge joins the cystic duct before it opens into the duodenum, just posterior to the whorl of pyloric caeca.

(v) *Histology of the alimentary tract*

Except in the region of the mouth, buccal cavity and pharynx, the wall of the alimentary tract is made up of five layers, viz. serosa, muscularis, submucosa, tunica propria and mucosa. The serosa is a thin layer of areolar tissue while the muscularis consists of a layer of circular and another of longitudinal muscle fibres. The submucosa consists of a layer of loose connective tissue through which pass small blood vessels; and the tunica propria is formed of areolar tissue. The mucosa is very variable in thickness and structure.

1. Buccal lining

The lining of the buccal cavity consists of mucosa and submucosa. The mucosa is made up of stratified epithelium supported below by a thick stratum compactum. Below it is a well-developed layer of connective tissue. The cells of the stratified epithelium are either columnar or cuboidal in shape, with large spherical or oval nuclei. An important feature of the stratified epithelium is the presence of pyriform mucus-secreting cells located towards the margin of the lining. Taste-buds could not be found in any of the several sections examined.

Below the stratified epithelium is a thin basement membrane made up of densely packed fibres. Below this is the stratum compactum composed of closely packed fibres. The submucosa is made up of areolar connective tissue supplied with numerous blood-vessels and some nerve fibres.

Transverse sections of the lips also did not show the presence of taste-buds.

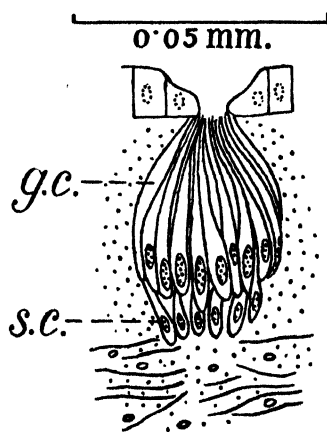
2. Pharynx

The pharyngeal wall comprises of the muscularis, submucosa and the mucosa.

Muscularis consists of a single layer of coarsely striated circular muscle fibres. It is thicker on the roof of the pharynx, than on its floor.

Submucosa is the thickest layer of the pharyngeal wall. The nuclei of the connective tissue are small and spherical. This connective tissue contributes to the formation of the papillary structures found in the mucosal region, by pushing out the stratum compactum. The connective tissue is seen to be supported by scattered bundles of striated muscle fibres on the outside where they form a separate layer.

Mucosa forms a number of high longitudinal folds, enclosing narrow and deep crypts. The basal layer of the stratified epithelium consists of low columnar cells with oval nuclei. The most notable feature is the presence of taste-buds (Plate XXXIV, Fig. 1 and Text-fig. 12), each spheroidal in shape and made up of elongate cells with long or ovoid nuclei. The gustatory cells converge towards a small depression. Another set of elongate cells known as sustentacular cells are seen at the base of the buds.



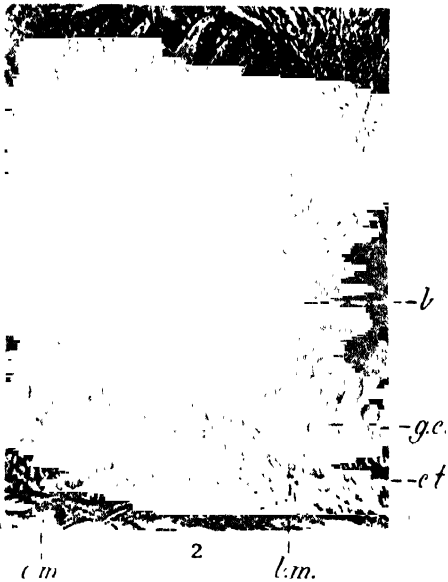
TEXT-FIG. 12. A taste bud from the pharyngeal cushion.

g.c.—Gustatory cell
s.c.—Sustentacular cell.

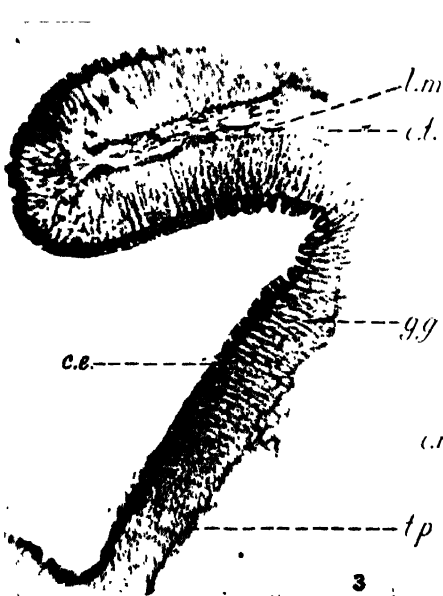
Taste-buds have not been noticed either on the lips or on the buccal lining, but their presence in the pharyngeal wall indicates that the fish is able to recognise its



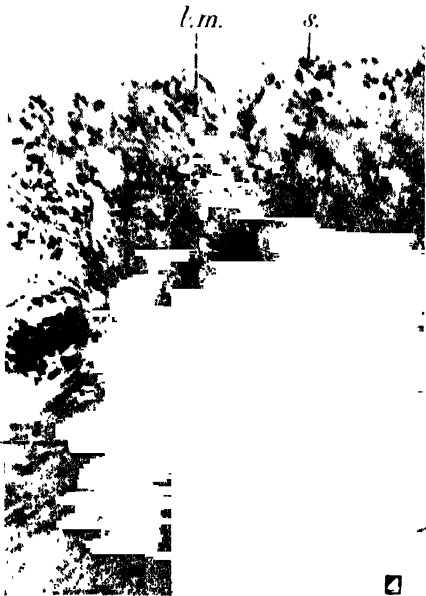
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food by taste, only in the pharynx. As has been already mentioned, it is in the pharynx that the food matter is sieved out from the extraneous particles.

The stratified epithelium is supported by basement membrane and the stratum compactum.

3. *Oesophagus*

Histologically the oesophagus is divisible into an oesophagus proper and an oesogaster as defined by Ghazzawi (1935).

Oesophagus proper (Plate XXXIV, Fig. 2). The oesophagus proper shows the following regions:—

Serosa, muscularis, submucosa, tunica propria and mucosa.

Serosa.—It is very thin and made up of a pavement epithelium with deeply staining nuclei. Blood vessels can be seen to pass through the subserous tissue into the muscularis.

Muscularis.—The muscularis consists of an outer longitudinal and an inner striated thick circular layer of fibres. These latter may be of help to the fish in swallowing food. The longitudinal fibres are less numerous and are scattered in the submucosal tissue.

Submucosa.—This consists of a narrow layer of closely packed connective tissue which supports the oesophageal folds of the epithelial layer.

Tunica propria.—It is very similar to the submucosa and can hardly be distinguished from it.

Mucosa.—It is composed of a layer of columnar epithelial cells with basally situated oval nuclei. Among the columnar cells are found several flask-shaped goblet cells in communication with the lumen into which the mucus secreted by them is discharged. This mucus is obviously meant to prevent the hard particles of food from coming into direct contact with the mucosal tissue and also to a certain extent to 'soften and lubricate the coarse food of the fish' as suggested by Ghazzawi (1935).

Oesogaster (Plate XXXIV, Fig. 3).—A cross-section of the oesogaster shows all the five regions found in the oesophagus proper. The general structure is also the same except in the mucosal layer. Also, the submucosa is not distinct as in the oesophagus proper.

The *mucosa* consists of an outer layer of numerous, densely packed gastric glands and an inner layer of columnar epithelium. The glands are bound together by connective tissue and are made up of elongated cells arranged end to end, forming a long and tubular structure. The spherical nuclei lie farthest from the narrow lumen. The glands open into the oesogaster at the crypts of the folds, with their opening not visible in all sections.

The columnar epithelium consists of long, slender, cylindrical cells, which form a highly wavy layer forming what are called 'gastric crypts.' The fanwise close arrangement of the cells at the crests of the crypts make them appear pear-shaped. The cells are columnar on the crypts as well as in the intermediate regions. The oval nuclei are located at the basal half of the cells.

The lumen of the oesogaster was found to contain large quantities of mucus as in the oesophagus proper.

4. *Stomach*

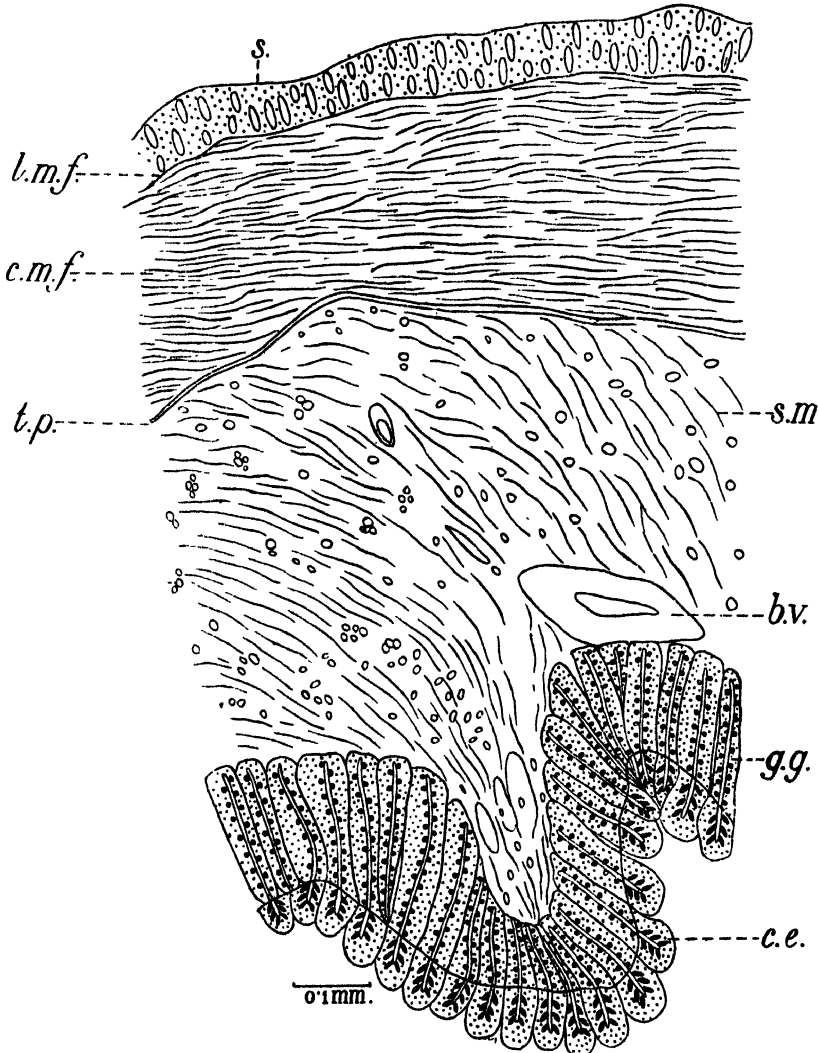
Cardiac Stomach (Plate XXXIV, Fig. 4, Plate XXXV, Fig. 1 and Text-fig. 13).—The cardiac stomach consists of two parts: a posterior epithelial part, and an anterior glandular part into which the oesogaster opens.

The wall of the cardiac stomach is made up of serosa, muscularis, submucosa, tunica propria and mucosa.

The *Serosa* is composed of a single thick layer of elliptical cells with deeply staining nuclei.

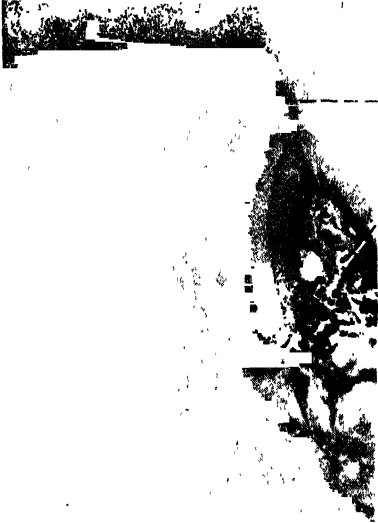
The *Muscularis* consists of an outer longitudinal and an inner much thicker circular layer of muscle fibres of the unstriated variety. A large number of blood vessels can be observed in the sections.

The *Submucosa* consists of a narrow layer of connective tissue beneath the muscularis, forming folds above the tunica propria.



TEXT-FIG. 13. The cross-section of the wall of the glandular stomach.

- s.—Serosa
- l.m.f.—Longitudinal muscle fibres
- c.m.f.—Circular muscle fibres
- t.p.—Tunica propria
- s.m.—Striated muscle fibres
- b.v.—Blood Vessel
- g.g.—Gastric gland
- c.e.—Columnar epithelium.



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The *Tunica propria* is made up of thick and interlacing strands and supports the glandular layer of the stomach.

The *Mucosa* consists of a columnar epithelium of closely arranged cylindrical cells, and a gastric epithelium in the glandular part of the cardiac stomach. In the crests of the folds, the former are arranged fanwise, with basally disposed oval nuclei. There is a thick layer of mucus lining the epithelium.

The glandular epithelium comprises of numerous tubular glands, the structure of which is similar to that of the glands in the oesogaster.

The presence of numerous blood vessels in the cardiac stomach indicates its absorptive function.

The Pyloric Stomach (Plate XXXV, Figs. 2 and 3).—The wall of the pylorus is made up of serosa, muscularis, tunica propria and the mucosa.

The Serosa is thin and has deeply staining nuclei.

The Muscularis is the thickest layer of the pylorus wall, consisting as it does of inner circular muscle fibres arranged in the form of rings separated by bands of connective tissue. The longitudinal muscle fibres are very much reduced. The muscularis probably helps the fish to triturate the food materials, and also by the contraction of its wall, push the food into the duodenum.

The Tunica propria is very narrow with densely packed strands.

The Submucosa consists of a thin layer of connective tissue.

The Mucosa with its prominent folds forms an epithelial layer with triangular projections supported by thin strands of connective tissue. The slender columnar cells have basally placed large nuclei. Several globular cavities resembling goblet cells are seen in this region. In all the sections examined, a thick fibrous layer could be noticed inside the epithelium, formed evidently by the secretion of the columnar epithelium for protecting it against rupture by direct contact with hard food materials. This appears to be the exceptionally thick 'horny epithelium' referred to by Ishida (1935) in *M. cephalus* and the mucus layer referred to by Ghazzawi (1935).

5. Duodenum and Intestine (Plate XXXV, Fig. 4)

The histological structures of the duodenum and the intestine proper are very similar, though the duodenal folds are more prominent. In both, the folds are narrow and pointed at their crests and broad at the base.

The Serosa is thin consisting of a layer of cells having deeply staining nuclei. The subserous connective tissue is clearly visible.

The Muscularis which is not very distinct consists of a thin layer of closely arranged tissue fibres.

The Tunica propria is a layer of areolar connective tissue well supplied with blood vessels, and supporting the mucosal folds. The blood vessels in the layer, with several scattered spherical or oval nuclei, absorb the digested food.

Mucosa.—The epithelium lining the mucosal folds consists of long and narrow columnar cells with basally placed nuclei, and mucus-secreting flask-shaped goblet cells with long and narrow prolongations at both ends, more numerous in the duodenum. The epithelial layer is lined with a 'top plate', which is striated in appearance. On this 'top plate' are situated apertures through which the mucus secreted by the goblet cells flow into the intestinal lumen.

The Pyloric caeca have the same structure and function as the duodenum.

6. Rectum

The rectum has a histological structure very similar to that of the intestine and consists of the serosa, muscularis, submucosa, tunica propria and mucosa, of which the muscularis and tunica propria are thicker than in the intestinal region. There are very large blood spaces in this tissue which evidently absorb the digested food matter.

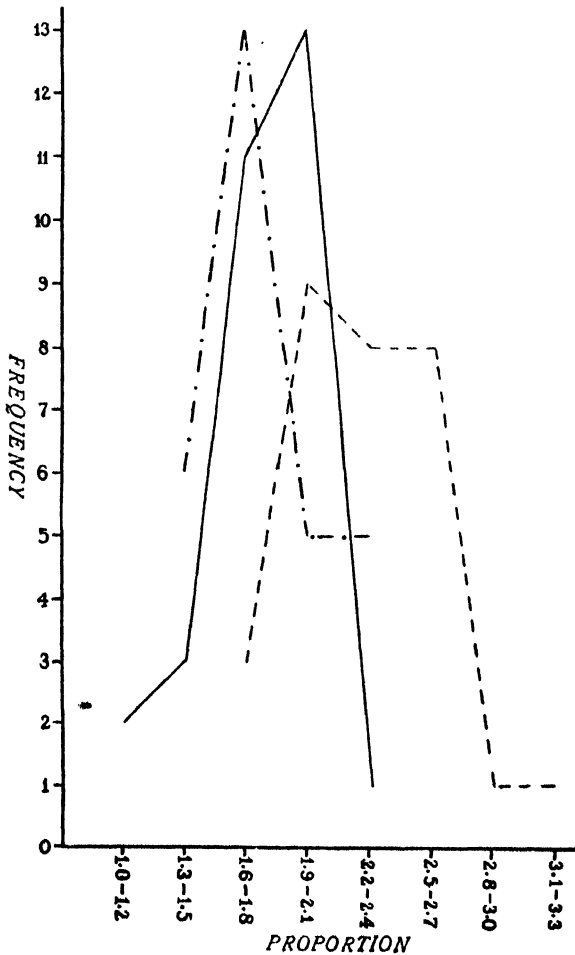
(vi) *Histology of Liver and Pancreas*

The liver is made up of polygonal cells with large spherical nuclei, interspersed with numerous blood capillaries and hepatic ductules scattered in the liver tissue which are made up of an inner cubical epithelium and an outer layer of thick connective tissue. Certain cells have granules of glycogen in them.

In transverse sections of the pancreas which consists mainly of large polyhedral cells with deeply staining nuclei, acini surrounded by a network of blood vessels can be seen. Faintly staining Islets of Langerhans are seen in irregular groups.

IV. RELATION BETWEEN NATURE OF FOOD AND LENGTH OF ALIMENTARY CANAL

The proportion of the length of the alimentary canal of *M. tade* to its total length ranged between 1 : 1 and 1 : 3.3. A comparative study of the lengths of the alimentary canal in formalin (5%) preserved specimens obtained from the sea,



TEXT-FIG. 14.—The graph showing the frequency distribution of the proportion of total length in length of alimentary tract for the different environments. Solid line represents estuarine specimens, dots and dashes represent marine specimens and broken line represent brackish water farm specimens.

Estuary and brackishwater farm was made, with random samples of 30 specimens from each of the three localities ranging from 43 mm. to 506 mm. in total length. In the natural habitats of the fish, *viz.*, the sea and estuary the average factor (proportion of total length to length of alimentary canal) was 1 : 1.8 (± 0.01042 for specimens from the sea and ± 0.00338 for specimens from the estuary) whereas in the enclosed brackishwater farm it was 1 : 2.3 (± 0.00327). Text-fig. 14 represents the frequency distribution of this factor in each of the three surroundings. It will be seen from this figure that the majority of the specimens from the sea had the factor between 1.6-2.1 whereas the majority of specimens from the farm showed the factor ranging from 1.9-3.0; and the majority of the estuarine specimens had the factor varying between 1.6 and 1.8.

It has already been shown that there is considerable difference in the nature of the food eaten by the fish in different types of environments. The relatively short alimentary canal of the fish from the estuary appears to be due to the easily digestible decayed organic matter on which it feeds. There is no marked difference in the lengths of the alimentary canal between the estuarine and marine specimens. But the majority of specimens from the sea showed a slightly higher value for the factors. This is to be explained by the comparatively larger quantities of diatoms and algae consumed by the fish in a marine environment. As already indicated the fish feed on copious quantities of Chlorophyceae and Myxophyceae in the enclosed brackishwater farm. For the digestion and absorption of this type of coarse food matter, a larger area of mucosal surface which is essential is provided by the longer alimentary canal.

This observation shows that the fish is capable of considerable morphological adaptation to the nature of available food. Schuster (1949) has observed marked variation in the intestinal length of *Chanos chanos* fed exclusively on one particular type of food, and probably because of that showed very remarkable difference in length. A more marked difference would probably be noticeable in the mullet also if similar experiments are conducted.

V. DISCUSSION

(i) *Nature of Food and Feeding*

A review of the diet tables proves beyond doubt that the fish obtains its diet, consisting mainly of fresh and decaying plant matter, from the iliotrophic layer on the substratum of its habitats, and so may be termed an iliophage.

This observation is not in agreement with that of Chacko and Venkatraman (*op. cit.*) and Jacob and Krishnamurthy (*op. cit.*). The mere presence of diatoms in the gut contents seems to have led them to conclude that mullets are plankton feeders.

The early fry feed on floating unicellular and colonial algae or attached marginal growths of algae. Miscellaneous animal matter, mostly appendages of copepods, moults of polychaetes, etc., found in the stomachs of adults and are accidental inclusions, proves only their bottom-feeding habits. The feeding of starved fish shows that animal matter may be devoured, but this cannot prove their carnivorous habits. Orton's (*op. cit.*) observations based on aquarium experiments may be explained only as an abnormal behaviour of the fish under artificial conditions. Kesteven (1942) was not able to find recognisable matter in the gut contents of *M. dobula*. But various algal forms and diatoms have been identified from the guts of *M. tade*. The observations of Mookerjee, Ganguly and Mazumdar (*op. cit.*) and Mookerjee, Ganguly and Sarcar (*op. cit.*) are in general agreement with mine. The findings of Hiatt (*op. cit.*) and of John mentioned briefly in his report (1948) have been fully corroborated by this investigation.

Hiatt (*op. cit.*) did not find any seasonal variation in the food of *M. cephalus*. In the present study the qualitative composition of the food of *M. tade* remained the same throughout the year, though the relative abundance of the different items varied, probably due to fluctuations in their availability.

(ii) *Correlation between alimentation and nature of food and feeding*

The morphological and histological features of the alimentary canal of the fish provide a clue to its food and feeding habits. The dorso-ventrally compressed conical head is admirably suited for marginal feeding. The relative size of the mouth (2.7 to 3.4 times in the total length of the head) is indicative of a predominantly algal diet (Schuster, *op. cit.*). According to Angelescu and Gneri (*op. cit.*) the special adaptations in the digestive apparatus of the iliophagous fishes are:

- (a) Suctorial type of mouth which lacks a well-developed set of teeth,
- (b) Well-developed filtering apparatus of the gills which is very efficient to separate the minute food components from the mud,
- (c) Generally a well-developed pyloric stomach, and
- (d) Long gastro-intestinal canal offering increased absorptive surfaces and specially organised mucosa.

The protrusible mouth of *M. tade* is well adapted for sucking in food materials from the muddy bottom. The mouth becomes definitely inferior in position when it is protruded, making bottom feeding feasible. The filtering apparatus formed by the pharyngeal cushions, pharyngeal teeth and the gill rakers, is admirably suited for filtering mud. The pyloric stomach is well developed and muscular. Such gizzard-like stomachs observed in *Mulloidies auriflamma* Forsk. (Wier and Churchill, 1945, quoted by Al-Hussaini, 1949) and *Dorosoma cepedianum* (Al-Hussaini, 1946), are helpful in crushing algal food, in view of the lack of any other masticatory apparatus. The study of the histology of the stomach has shown that the oesogaster and the stomach of *M. tade* contain gastric glands as in *M. capito* (Ghazzawi, 1935) unlike as in *M. cephalus* (Ishida, *op. cit.*). The mucus secreted in the different parts of the alimentary tract prevents the hard food particles from coming into contact with the mucosal lining. It has already been shown how the food consumed determines the length of the alimentary canal. The great length of the intestine offers a large mucosal surface for absorption of food matter. The mucosa of the stomach is well protected from coming into direct contact with the hard particles that are likely to be present in an iliophagous type of food. Thus it will be clear that the alimentary tract of *M. tade* is well adapted for an iliophagous type of food in its morphology and histology.

The change in food habits when the early fry grow into adults bears close correlation with the development of the alimentary features. It has already been shown that the development of the processes of the gill rakers and of the pharyngeal teeth takes place only when the fish grows to lengths of 47 mm. and 62 mm. respectively. Efficient sieving of food matter from mud appears to be possible only at this stage of development, and consequently bottom feeding appears to start only then.

(iii) *Food Habits in different environments*

Another fact brought to light by the present studies is that with the change of habitat, the food habits of the fish also change to a considerable extent. The pie diagrams (Text-fig. 1) represent the volumetric composition of food of the fish in the four different types of environments. This remarkable difference in food habits is to be correlated with the availability and abundance of food items in the particular surroundings, rather than with a change of its tastes. This will be evident from the histograms (Text-fig. 2) representing the food of the fish in different localities as analysed by the occurrence method.

The food components remain the same in all the four ecological surroundings, the difference being only in the relative proportions of the various items. Algae, diatoms and decayed matter appear to be available in nearly equal quantities on its feeding grounds in the sea and naturally they have been eaten in nearly equal quantities. In the enclosed brackishwater farms and freshwater tanks, algal growth is profuse and so algae predominate as an item of food in these surroundings. With the meagre knowledge we have of the migratory movements of mullets, it is not possible to state definitely as to how far availability and nature of food influence their migrations. Fish in the IV and V stages of gonadal development were found to be feeding normally, but as actual spawners were not available for study it cannot be stated at present, whether feeding ceases during the spawning period.

(iv) Food of Major Associates of Mulletts in Farms

The food and feeding habits of *M. tade* are very similar to those of the milk fish *Chanos chanos* (Sunier, 1922). Both feed at the bottom and suck in diatoms, preferring soft decayed algal filaments. The muscular gizzard-like stomach and the long coiled intestine are features common to both; and with change in the nature of food eaten, the alimentary canals in both the fishes vary in length. Schuster (1949a) found that the tough filaments of algae (*Enteromorpha*) were not easily digested by *Chanos*. The same appears to be the case with the mullet which has no masticatory apparatus in its mouth. The only organ meant to crush hard food is the gizzard as in the case of *Chanos*, but this cannot possibly crush very tough substances.

The close similarity between the milk fish and the mullet in feeding habits points to the desirability of examining the question of growing them together in the same ponds as is done in South India. Since they feed in the same manner on the same type of food and thus compete with each other they cannot be considered suitable associates in farms. Hiatt (*op. cit.*) has also made a similar observation from a study of the food chain in Hawaiian fish ponds. Pillay (1949) has reported the successful practice in Bengal of culturing mullets in association with commercial carps on lines somewhat similar to those practised in Hongkong (Lin, 1940). True, some of the carps feed on decayed plant matter, but in deep tanks mullets prefer to feed on the margins and do not greatly interfere with the feeding of carps. In the brackishwater farms near Calcutta, the main associates of mullets are the Bhekta (*Lates calcarifer*), Tengra (*Mystus gulio*), and prawns (*Penaeus spp.*, *Metapenaeus spp.* and *Leander spp.*). Of these, *Lates calcarifer* is unsuited as a pond associate in view of its predaceous nature and its preference for mullets (Menon, 1947). In view of its generally omnivorous habit, the cat-fish (*Mystus*) is not a keen competitor to the mullet for food. The prawns feed on algae and decayed organic matter on which mullets also feed. Thus it will be seen that the majority of the farm associates of mullets in brackishwater *bheris* of Bengal are not complementary in food habits.* Obviously, the most suitable associates for mullets would be surface feeders that will utilise the surface plankton of the *bheris*.

(v) Suggestions for increasing food of Mulletts in farms

A consideration of the food of the mullet raises the question of stepping up the production of their favoured food items in the farms. The *Chanos* farmers of South-East Asia have devised methods of raising rich growths of *lab-lab*, a plant complex composed of unicellular, colonial and filamentous blue-green algae (chiefly of the family *Oscillatoriaceae*), diatoms, etc., and *lumut*; the filamentous

* A detailed account of the food relations of the major associates of mullets in *bheris* will be published elsewhere.

green algae consisting of *Cladophora*, *Enteromorpha*, *Vaucheria*, *Spirogyra*, *Chaetomorpha* and *Oedogonium* (Herre and Mendoza, 1929; Adams, Montalban and Martin, 1932; Carbine, 1948; and Rabanal, 1949). In view of the fact that the food of the mullet is similar to that of the milk fish, it should be beneficial to adopt in mullet farms the methods followed to promote algal growth in *Chanos* farms. Preliminary studies have indicated that algal production is best in ponds with soil having a high 'solution loss', high content of clay, nitrogen and organic matter (Rosell and Argülles, 1936 and Carbine, *op. cit.*). The bottom soil of mullet farms near Calcutta consists of heavy mud composed of tenacious loam, mixed with a good proportion of humus. This type of soil might therefore be quite suitable to raise the *lab-lab* and *lumut* type of algal growths.

Hora and Nair (*op. cit.*) advocated pond cultural methods such as manuring, for increased production from *bheris*. They recommended both chemical as well as organic manures for application in *bheris*. The use of chemical manures have two disadvantages. Firstly, they are, when available, too costly for the average fish culturist. Secondly, the immediate effect of the application of chemical fertilizers is the production of plankton. How far the growth of the bottom flora will be influenced by this practice, has not yet been established (Marshall, 1947). Schuster (1949b) reports that experiments with artificial manure did not show any results in Javanese fish ponds. However, organic manure will be highly suitable for more than one reason. Organic manure, if kept on the farm bottom, will be utilised only slowly and will promote the growth of bottom algae and diatoms. Decaying organic matter may also be directly eaten by the fish. Its cheapness and easy availability in the swampy areas render it the most suitable type of manure for mulletries. In Java 'leaves of mangroves, grasses from the embankments, aquatic plants from inland ponds and in exceptional cases, rice straw are thrown into the stocked ponds or deposited in piles on the bottom' for the purpose (Schuster, 1949b). Similar types of organic manures are easily available near the *bheris* in Bengal, and can be utilised for manuring purposes with practically no outlay.

Regular draining and drying of pond bottom is widely practised in Indonesia and Philippines to stimulate the growth of blue-green algae. The fish farmers know by experience that drying the soil for 2-3 days usually results in an increase in the growth of the thick mat of blue-green algae if the bottom soil is rich in organic matter. It will thus be advisable for our mullet culturists to drain and dry their farms regularly to raise the production of algae. Just before the stocking season, the *bheris* can be drained, and exposed to the sun for drying before letting in water and fry.

Another practice likely to help the growth of algae in farms is the provision of sufficient submerged stones or pieces of wood on which algae developing from spores can attach themselves and grow. Villadolid and Villaluz (1949) suggested the provision of 'collectors' made of twigs and branches of mangrove trees, for the attachment of spores in deep *Chanos* ponds. Twigs paved in trellis work fashion along the margins of farms may serve to increase the growth of attached algae, and the fry will specially be benefited by this.

VI. SUMMARY

The food and feeding habits of *M. tade* were studied by the examination of gut contents and observations in the field and aquaria.

483 specimens of *Mugil tade* ranging from 15 cm. to 53.8 cm. collected from the sea, estuary, brackishwater-farm and freshwater tanks during different months of the year were studied in detail. It was found that the fish is an iliophage, decayed organic matter, filamentous algae and diatoms forming its food. Considerable difference was observed in the relative proportions of the food components in the four environments. Algae, diatoms and decayed matter are eaten in nearly equal quantities in the sea. In the estuary, decayed matter was the predominant item of food; and in the brackishwater farm and freshwater tanks algae formed the chief item. Miscellaneous animal matter often occur in the gut contents. But they appear to have been

aten only accidentally, while feeding on algae, decayed matter, etc. Fine sand grains are invariably met with in the stomachs of fingerlings and adults. The fish is a bottom or marginal feeder and the shape of its snout and mouth are adapted for such a type of feeding.

Early juveniles (up to 2 cm. in length) feed mainly on algae (Myxophyceae) at the surface or in the littoral regions. Fry 2.1-4.6 cm. in length begin to feed on decayed organic matter, and on considerable quantities of miscellaneous organisms, such as copepods, cladocerans and mysids. Fish, 6.1 cm.-8 cm. in length, show the adult feeding characters of bottom-feeding.

Specimens in the IV and V stages of sexual maturity were found to be feeding normally. Considerable fluctuations were observed in the abundance of the different items of food consumed during different seasons of the year. The analyses of gut contents have revealed a marked increase in the feeding activity during the winter season.

Feeding experiments in aquaria have shown that the fish prefer algae, especially those rendered soft by decay; and only when this is not available do they take to feeding on decayed matter in mud. Starved specimens do consume micro-zooplankton and peck at even bigger animalcules, which they are unable to swallow. A study of the morphology and histology of the alimentary tract and connected glands was made in order to elucidate their correlation with the food and feeding habits of the fish. The mouth of *M. tade* is inferior in position and its width is contained about 2.7 to 3.4 times in the length of its head, a dimension typical of herbivores. There is a constant linear relationship between the total length of the fish and the width of the mouth. The protrusible mouth makes it possible for the fish to suck in mud. The mechanism of deglutition is described. The presence of numerous taste buds in the pharyngeal wall suggests that the fish is able to recognise its food in the pharynx, where the actual sieving out of food matter takes place. The fish has a very efficient pharyngeal filtering apparatus formed by the gill rakers and the pharyngeal cushions. The mechanism of filtration of food matter is described. The morphological and histological features and functions of the oesophagus, stomach, duodenum, intestine and rectum as well as the connected glands are presented. The suctorial type of mouth, the pharyngeal apparatus specially suited for filtering out food components from mud, the well-developed pyloric stomach and a long gastro-intestinal canal with specially organised mucosa, are adaptations for iliophagous feeding on the benthic zones. It is shown that the length of the alimentary canal varies with the nature of the food consumed. Fish raised in an enclosed farm, where algae formed the predominant food, had a longer alimentary canal than fish from the sea and estuary where the percentage of algal food consumed was relatively low. The features of alimentation prove conclusively that the fish is adapted for feeding at the bottom and in marginal areas on plant matter contained in the mud.

A consideration of the food of the common associates of mullets in the *bheris* shows that the majority of them are not complementary in food habits.

A very close similarity was observed in the food, feeding habits and morphological features of the alimentary tracts of the mullet and of the milk fish (*Chanos chanos*). The adoption of practices allied to those devised by the *Chanos* farmers may help in the increased production of food for mullets in farms and contribute to better yields.

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EXPLANATION OF PLATES.

Plate XXXIII.

- FIG. 1. Sample of the gut contents of the fish from marine environment.
- FIG. 2. Sample of the gut contents of the fish from brackishwater farm.
- FIG. 3. The stomach gorged with food (left) and the stomach with little food (right).
- FIG. 4. The sieving apparatus of the gills.
- FIG. 5. The roof of the buccal cavity showing the pharyngeal cushions.
p.—Pharyngeal cushion.
r.—Ridges.
- FIG. 6. A longitudinal section of the stomach and the oesophagus.
c.s.—Cardiac stomach.
oes.—Oesophagus.
p.s.—Pyloric stomach.

Plate XXXIV.

- FIG. 1. Photomicrograph of the cross-section of the pharyngeal cushion showing the taste buds.
FIG. 2. Photomicrograph of the cross-section of the wall of the oesophagus proper.
FIG. 3. Photomicrograph of the cross-section of the wall of the oesogaster.
FIG. 4. Photomicrograph of the cross-section of the serosa and muscularis of the non-glandular part of the stomach.

c.e.—Columnar epithelium.
c.m.—Circular muscle fibres.
c.t.—Connective tissue.
g.c.—Goblet cells.
g.g.—Gastric glands.
l.—Lumen.
l.m.—Longitudinal muscle fibres.
s.—Serosa.
s.e.—Stratified epithelium.
t.b.—Taste bud.
t.p.—Tunica propria.

Plate XXXV.

- FIG. 1. Photomicrograph of the cross-section of the mucosa and sub-mucosa of the non-glandular part of the stomach.
FIG. 2. Photomicrograph of the cross-section of a part of the pyloric stomach.
FIG. 3. Photomicrograph of the cross-section of the mucous layer in the pyloric stomach.
FIG. 4. Photomicrograph of the cross-section of the duodenum.

c.e.—Columnar epithelium.
c.t.—Connective tissue.
g.c.—Goblet cells.
l.—Lumen.
m.—Mucous layer.
m.c.—Mucus secreting layer.
s.—Serosa,
t.p.—Tunica propria.

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ON THE INTERNAL BALLISTICS OF LEAKING GUNS

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1. INTRODUCTION

A theory of the internal ballistics of leaking guns has been developed by J. Corner (1947 and 1950). By adding to the assumptions usually made in the theory of conventional guns the further assumption that the setting up of the gas-flow through the nozzle can be represented by the equations for one-dimensional quasi-steady flow beginning instantaneously at a certain pressure (called the 'nozzle-start pressure'), he derived a set of equations which generalise those for a conventional gun and involve two new parameters: (a) the leakage parameter Ψ , which is constant if the throat-area is constant during the firing, (b) the epoch of the opening of the nozzle. This system of equations can always be integrated numerically. However, in the case when the rate of burning is proportional to the pressure, Corner gave a more rapid method which consists in replacing certain mean values occurring in the theory by simple analytical expressions suggested by a study of a large number of numerical integrations and integrating the resulting equations analytically. We shall refer to this as 'Corner's analytical method'.

A still simpler method, also due to Corner, consists in a reduction to an 'isothermal model', by giving the temperature a suitable mean value throughout the period of burning. This reduces the equations for the leaking gun to those for an equivalent conventional gun. The method is of considerable value in obtaining quick estimates of the effects produced by gas leakage. However, the 'isothermal' assumption is inconsistent with the energy equation and in fact it is easily verified that in the above-mentioned reduction to an equivalent conventional gun, the energy equation does not reduce to the corresponding equation for the equivalent gun. Nevertheless, the result that the changes in the various ballistic quantities produced by the gas leakage are all linear in the leakage parameter Ψ —a conclusion derived by Corner on the basis of this method—is important. One would expect that such a conclusion had a more general basis than the special assumptions from which Corner derived it. In fact, on account of the smallness of the values of Ψ involved,† it seems natural to attempt to solve the general equations for a leaking gun by a method of successive approximations based on an expansion in powers of Ψ ; the first-order terms in such a series-solution should correspond to the linear correction terms derived by Corner.

In this paper we have carried out the above procedure of successive approximations and have calculated the solution up to the first order in Ψ . We find that the method gives a reasonably simple means of obtaining, without elaborate calculations, all the ballistic information of interest such as the maximum pressure,

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† For smooth-bore guns and mortars Ψ is of the order 0.1, while for recoilless guns with tubular propellant the values of Ψ lie in the range 0.4–0.6. Even in the latter case the method of successive approximations gives satisfactorily accurate results, as shown by the example at the end of the paper.

the relation between the shot-start and the nozzle-start pressures, and the variation in the gas temperature during burning. A comparison of the results for a particular example obtained by the present method with those derived by Corner's analytical method indicates that our approximation procedure compares favourably with the more accurate and elaborate methods.

2. THE FUNDAMENTAL EQUATIONS FOR A LEAKING GUN

We assume that (a) the rate of burning is proportional to the pressure, (b) the propellant is tubular, (c) the initial resistance is represented by a shot-start pressure, bore-resistance being neglected, (d) the setting up of the nozzle-flow can be represented by the use of the equations for quasi-steady nozzle-flow beginning instantaneously at a certain pressure called the nozzle-start pressure, (e) no unburnt propellant is lost through the nozzle. With the nozzle open, shot in motion and charge not completely burnt, we shall then have the following equations (in the usual notation (H.M. Stationery Office, 1951)).

$$p(K_0 + Ax - C/\delta) = CNRT \left(1 + \frac{kCN}{6W} \right) \quad \dots \quad (1, a) *$$

$$W_1 \frac{d^2x}{dt^2} = Ap \quad \dots \quad (1, b)$$

$$W_1 = W + \frac{1}{2} kCN \quad \dots \quad (1, c) \dagger$$

$$D \frac{df}{dt} = -\beta p \quad \dots \quad (1, d)$$

$$z = 1 - f \quad \dots \quad (1, e)$$

$$\frac{dN}{dt} = \frac{dz}{dt} - \psi Sp / C(RT)^{\frac{1}{2}} \quad \dots \quad (1, f)$$

$$\frac{d(NT)}{dt} = -(\bar{\gamma} - 1) \frac{Ap}{CR} \frac{dx}{dt} + T_0 \frac{dz}{dt} - \frac{\gamma \psi Sp(RT)^{\frac{1}{2}}}{CR} \dots \quad (1, g) \ddagger$$

These equations differ from those for a corresponding conventional gun in the following respects: (i) the altered Lagrange correction-factors in (1, a) and (1, c), (ii) the appearance of an additional term on the right of the energy equation (1, g) to allow for the loss of energy by the gas-flow through the nozzle, and (iii) the addition of a new relation, the nozzle-flow relation (1, f).

The above set of equations may be reduced to non-dimensional form by introducing the following dimensionless variables and parameters:—

$$Al = K_0 - C/\delta \quad \dots \quad (2, a)$$

$$\xi = 1 + \frac{x}{l} \quad \dots \quad (2, b)$$

$$\tau = (\beta CRT_0 / ADl) t \quad \dots \quad (2, c)$$

* The l.h.s. of Eq. (1, a) has been somewhat simplified by neglect of certain terms representing covolume effects.

† Corrections for recoil, if any, rotational inertia and bore-resistance may be included in W .

‡ A derivation of the energy equation different from that given by Corner is to be found in *Def. Sci. Jl.*, 2, 1952, pp. 206-7. Heat loss to the barrel is taken into account by changing γ into $\bar{\gamma}$ in the first term on the right in (1, g).

$$\zeta = (Al/CRT_0) p \quad \dots \quad (2, d)$$

$$\eta = d\xi/d\tau = \frac{AD}{C\beta RT_0} \frac{dx}{dt} \quad \dots \quad (2, e)$$

$$T' = T/T_0 \quad \dots \quad (2, f)$$

$$M = A^2 D^2 / \beta^2 CRT_0 W \quad \dots \quad (2, g)$$

$$\Psi = \psi SD / \beta C (RT_0)^{\frac{1}{2}} \quad \dots \quad (2, h)$$

Then the equations (1) become:—

$$\zeta \xi = NT' (1 + kCN/6W) \quad \dots \quad (3, a)$$

$$\eta \frac{d\eta}{d\xi} = \left(\frac{M}{1 + \frac{kCN}{2W}} \right) \zeta \quad \dots \quad (3, b)$$

$$df/d\tau = -\zeta \quad \dots \quad (3, c)$$

$$z = 1 - f \quad \dots \quad (3, d)$$

$$\frac{dN}{d\tau} = \frac{dz}{d\tau} - \Psi \zeta (T')^{-\frac{1}{2}} \quad \dots \quad (3, e)$$

$$\frac{d(NT')}{d\tau} = -(\bar{\gamma} - 1) \zeta \frac{d\xi}{d\tau} + \frac{dz}{d\tau} - \gamma \Psi \zeta (T')^{\frac{1}{2}} \quad \dots \quad (3, f)$$

Let z_0, z_N denote the values of z at shot-start and nozzle-start respectively. Then

$$\eta = 0 \text{ for } z = z_0 \quad \dots \quad (4, a)$$

$$N = z \text{ for } z \leq z_N \quad \dots \quad (4, b)$$

From (3, b), (3, c) and (3, d) we have

$$\frac{d\eta}{d\tau} = \eta \frac{d\eta}{d\xi} = \frac{M}{1 + kCN/2W} \frac{dz}{d\tau} \quad \dots \quad (5)$$

The factor $1 + \frac{kCN}{2W}$ has a value close to unity throughout the period of burning.

Replacing it by an average value $\sigma (\sigma \sim 1)$ we have

$$\frac{d\eta}{d\tau} = \frac{M}{\sigma} \frac{dz}{d\tau}$$

so that using (4, a):

$$\eta = \frac{M}{\sigma} (z - z_0) \quad \dots \quad (6)$$

Again from (3, c), (3, d) and (3, e) we have

$$\frac{dN}{d\tau} = \frac{dz}{d\tau} - \Psi (T')^{-\frac{1}{2}} \frac{dz}{d\tau}$$

whence, using (4, b), we get

$$N = z - \Psi \int_{z_N}^z (T')^{-\frac{1}{2}} dz \quad \dots \quad (7)$$

Further, from (3, b), (3, c), (3, d) and (3, f) we get

$$\frac{d}{d\tau}(NT') = -\frac{(\bar{\gamma}-1)\sigma}{M}\eta\frac{d\eta}{d\tau} + \frac{dz}{d\tau} - \gamma\Psi(T')^{\frac{1}{2}}\frac{dz}{d\tau} \quad \dots \quad (8)$$

Assuming that the nozzle opens before the shot starts to move this gives on integration

$$NT' = -\frac{(\bar{\gamma}-1)}{2M}\sigma\eta^2 + z - \gamma\Psi \int_{z_N}^z (T')^{\frac{1}{2}} dz \quad \dots \quad (9)$$

Substituting for η and M from (6) and (7) we get

$$zT' - \Psi T' \int_{z_N}^z (T')^{\frac{1}{2}} dz + \gamma\Psi \int_{z_N}^z (T')^{\frac{1}{2}} dz = A(z) \quad \dots \quad (10)$$

where

$$A(z) = z - \frac{1}{2}\sigma M(\bar{\gamma}-1)(z-z_0)^2 \quad \dots \quad (11)$$

If the shot starts before the nozzle opens, the equation (10) still holds, but with $\Psi = 0$ until the nozzle opens. The solution of the system of equations (3) is thus reduced to the solution of the single equation (10) for T' . When T' is obtained from (10) as a function of z , we find N from (7) and NT' from (9). To obtain ξ we eliminate ζ between (3, a) and (3, b):

$$\eta \frac{d\eta}{d\xi} = \frac{M}{\sigma} \frac{NT'}{\xi} \left[\frac{\sigma}{1 + \frac{kCN}{3W}} \right] = \frac{3M}{1+2\sigma} \frac{NT'}{\xi}$$

This gives on integration

$$\log \xi = \frac{1+2\sigma}{3M} \int_0^\eta \frac{\eta d\eta}{NT'}$$

or from (6),

$$\log \xi = \frac{M}{3} (1+2\sigma) \int_{z_0}^z \frac{(z-z_0) dz}{NT'} \quad \dots \quad (12)$$

Finally the pressure ζ is given by (3, a):

$$\zeta = \frac{3\sigma}{1+2\sigma} \frac{NT'}{\xi} \quad \dots \quad (13)$$

3. THE APPROXIMATE SOLUTION OF THE EQUATIONS

We first transform (10) by introducing a new variable u defined by

$$u = \int_{z_N}^z (T')^{\frac{1}{2}} dz \quad \dots \quad (14)$$

Then the equation (10) goes over into

$$z \left(\frac{du}{dz} \right)^2 + \gamma \Psi u - \Psi \left(\frac{du}{dz} \right)^2 \int_0^u \left(\frac{dz}{du} \right)^2 du = A(z). \quad \dots \quad (15)$$

We shall write this in the form:

$$z \left(\frac{du}{dz} \right)^2 - A(z) = \Psi \left[\left(\frac{du}{dz} \right)^2 \int_0^u \left(\frac{dz}{du} \right)^2 du - \gamma u \right]. \quad \dots \quad (16)$$

To solve this equation we substitute for u an expansion in powers of Ψ :

$$u = u^{(0)} + \Psi u^{(1)} + \Psi^2 u^{(2)} + \dots \quad \dots \quad (17)$$

and determine the coefficients of the successive terms in this expansion by comparing coefficients of powers of Ψ on both sides of (16). On account of the smallness of the value of Ψ in most practical cases, we confine ourselves to calculating the terms only up to the first order in Ψ . We thus get

$$z \left[\frac{du^{(0)}}{dz} \right]^2 = A(z)$$

so that

$$u^{(0)} = \int_{z_N}^z \frac{A(z)}{z} dz \quad \dots \quad (18)$$

and

$$z \frac{du^{(1)}}{dz} - \frac{1}{2} \left[\left\{ \frac{A(z)}{z} \right\}^{\frac{1}{2}} \int_{z_N}^z \left\{ \frac{z}{A(z)} \right\}^{\frac{1}{2}} dz - \gamma \left\{ \frac{z}{A(z)} \right\}^{\frac{1}{2}} \int_{z_N}^z \left\{ \frac{A(z)}{z} \right\}^{\frac{1}{2}} dz \right] \dots \quad (19)$$

To the same order we have, from (7) and (9),

$$N = z - \Psi \int_{z_N}^z \frac{dz}{du^{(0)}} dz = z - \Psi \int_{z_N}^z \left\{ \frac{z}{A(z)} \right\}^{\frac{1}{2}} dz \quad \dots \quad (20)$$

$$NT' = A(z) - \gamma \Psi u^{(0)} = A(z) - \gamma \Psi \int_{z_N}^z \left\{ \frac{A(z)}{z} \right\}^{\frac{1}{2}} dz \quad \dots \quad (21)$$

These give N and NT' explicitly as functions of z , from which we can immediately derive the variation of T' with z . Also the substitution for NT' from (21) in (12) gives ξ as a function of z and thence ζ is given by (13). Thus the determination of all the ballistic quantities is reduced to the evaluation of a number of integrals. These integrals can be easily calculated in any particular case by use of any of the standard formulae for approximate quadrature, such as Simpson's Rule. If, however, we assume that z_0 and z_N are small (as is usually the case), we may expand the integrands of the various integrals in powers of z_0 and z_N and retain only the terms up to the first order in z_0 and z_N ; then the resulting integrals can all be evaluated in closed form in terms of elementary functions. In general, this latter procedure is much more laborious and it is preferable to evaluate the integrals by numerical quadrature.

4. THE MAXIMUM PRESSURE

By differentiating (13) we find that the maximum pressure occurs when

$$\frac{d}{dz} (NT') = NT' \frac{d}{dz} (\log \xi).$$

Substituting from (12) and (21) for $\log \xi$ and NT' respectively and denoting by z_1 the value of z at which the maximum pressure occurs, we obtain the following equation for determining z_1 :

$$A'(z_1) - \gamma \Psi \{A(z_1)/z_1\}^{\frac{1}{2}} = \frac{M}{3} (1+2\sigma) (z_1 - z_0) \quad \dots \quad (22)$$

This equation may be solved by the method of successive approximations. We first neglect the term in Ψ and solve the equation to get a first approximation to z_1 . Since $A'(z)$ is linear in z this is very easily done. We next substitute this approximate value for z_1 in the coefficient of Ψ in (22), and again solve for z_1 to get an improved value for the root. Thus we can calculate z_1 from (22) to any desired degree of accuracy. The peak pressure ζ_1 is then calculated from (21), (12) and (13).

We next turn to the relation between maximum pressure and nozzle-start pressure for a prescribed value of the shot-start pressure. If the nozzle opens earlier than the shot-start, ($z_N < z_0$) it is clear that, with a prescribed shot-start pressure, the epoch of the shot-start will depend on that of the nozzle-start. In fact from (13) we have for $z = z_0$

$$x = 0, \quad \xi = 1, \quad \zeta_0 = \frac{3\sigma}{1+2\sigma} (NT')_0,$$

and so from (21) and (11),

$$\zeta_0 = \frac{3\sigma}{1+2\sigma} [z_0 - \gamma \Psi (z_0 - z_N)]$$

For a given value of ζ_0 , Eq. (23) gives a linear relationship between z_0 and z_N for the case $z_N < z_0$. There is no such relationship between z_N and z_0 in the case when the nozzle opens later than the shot-start. For $z_N < z_0$ the values of z_0 corresponding to different values of z_N are calculated from (23), while for $z_N > z_0$, z_0 has the fixed value $3\sigma\zeta_0/(1+2\sigma)$. In either case the values of ζ_1 for different values of z_N are calculated as above and we obtain the relationship between the peak pressure and the nozzle-start pressure. The curve thus obtained in the example worked out below (§ 5) (Fig. 1) is of the same general form as that obtained by Corner.

5. ILLUSTRATIVE EXAMPLE

In order to check the accuracy of the results obtained by the method outlined above, we have applied it to a hypothetical gun for which the ballistics have been worked out by H. N. Ware (1944) by Corner's more exact method. The results obtained by the present method and those obtained by the more exact methods are collected below for purposes of comparison.

TABLE I

<i>Peak pressure in tons/sq. in. Comparison of results obtained by different methods</i>				
Method of 'RD 38' (isothermal model)	..	..	..	13.13
Approximation method ..	..	..	..	12.77
Corner's analytical method ..	..	..	..	12.75

TABLE II

Variation of peak pressure (p_1) with nozzle-start pressure (p_N)

p_N (tons/sq. in.)			p_1 (tons/sq. in.)	
0	12.77
1	12.60
2	12.42
3	12.87
4	13.32

It will be seen that the value of the peak pressure calculated by the present method agrees quite well with that obtained by Corner's method. The variation of peak pressure with nozzle-start pressure is plotted in Fig. 1, and exhibits the characteristic features made familiar by Corner's work: the initial decrease of p_1 till p_N becomes equal to p_0 , followed by a steady increase, with a discontinuity in slope at $p_N = p_0$.

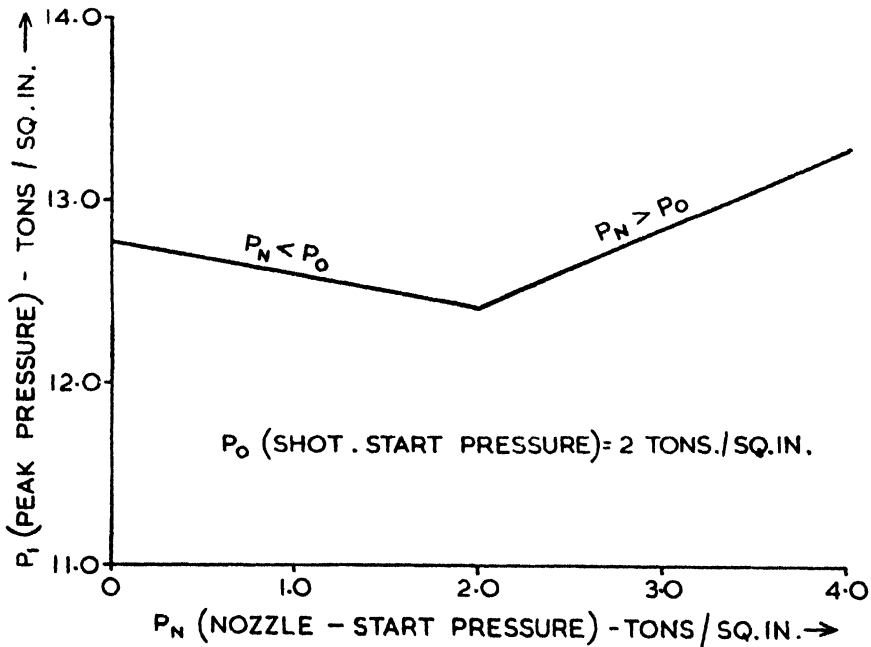


FIG. 1

A further check on the accuracy of the present method is provided by calculating from (20) and (21) the variation of T' during the period of burning; the values so obtained are shown in Table III.

TABLE III

Variation of T'

z$	..	..	..	T' - T/T_0$
0.2	..	..	..	0.834
0.4	..	..	..	0.796
0.5	..	..	..	0.782
0.6	..	..	..	0.768
0.8	..	..	..	0.742
1.0	..	..	..	0.717

The results are plotted in Fig. 2.

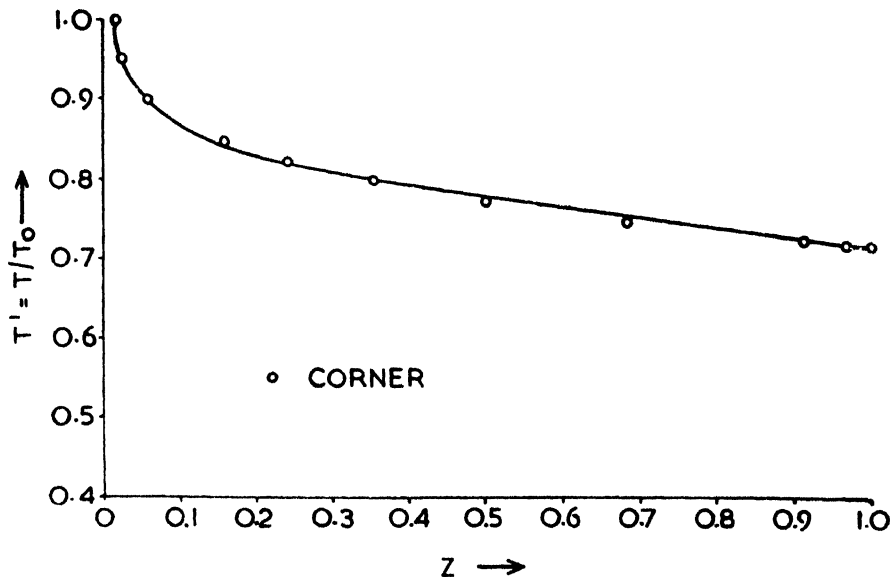


FIG. 2

In his analytical method Corner introduces the mean value defined by

$$\frac{1}{\nu_1} = \frac{1}{f - f_N} \int_{f_N}^f (T')^{-\frac{1}{2}} df \quad \dots \quad (24)$$

On the basis of a series of numerical integrations Corner finds (*loc. cit.*, 1950, p. 268) that it is sufficiently accurate to take

$$\nu_1 = \frac{1}{4} (1 + 3\sqrt{T'}) \quad \dots \quad (25)$$

Combining (24) and (25) and introducing z in place of f , we get

$$\int_{z_N}^z (T')^{-\frac{1}{2}} dz = 4(z - z_N)/(1 + 3\sqrt{T'})$$

from which we can solve for T' in the form

$$(1 + 3\sqrt{T'}) (1 - \sqrt{T'})^3 = B(z - z_N) \quad \dots \quad (26)$$

where B is a constant of integration.

In order to compare the values derived from (26) with the results obtained above, we have adjusted the constant B so that the value of T' for $z = 1$ agrees with that in Table III. The values of T' then obtained from (26) for several values of z are also plotted in Fig. 2. It will be seen that the points lie closely enough on the curve obtained by our method, giving a satisfactory check on the latter.

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SUMMARY

The equations of the interior ballistics of leaking guns are integrated by a method of successive approximations and the solution is worked out to terms of the first order. The application of the method to a particular example gives results in satisfactory agreement with those obtained by more accurate and elaborate methods.

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A THEOREM ON SETS OF POINTS

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In a recent paper on 'Non-Concyclic Sets of Points', Dr. Hansraj Gupta (1953) stated and proved that—

If a finite number of distinct points in a plane are such that a circle through any three of them passes through a fourth, then all the points lie on a circle.

This he stated in analogy to the theorem on straight lines conjectured by Sylvester and proved by Grünwald.

In this note it is shown that the above result of Dr. Gupta can be established under less restrictive conditions. It will be proved that—

If a finite number of distinct points in a plane are such that a circle through a particular fixed point of the set and any two other points of the set always passes through a fourth member of the set, then all the points are concyclic.

For, let p_i ($i = 1, 2, \dots, n$) be n points such that whenever $2 \leq r \leq n$, $2 \leq s \leq n$ and $r \neq s$ the circle $p_1 p_r p_s$ passes through p_t for at least one t , $2 \leq t \leq n$ and $t \neq r$ and s .

Inverting the system w.r.t. p_1 , we obtain a set of $n-1$ points p'_i ($i = 2, 3, \dots, n$) which are inversions of p_i ($i = 2, 3, \dots, n$).

Circles $p_1 p_r p_s$ invert into straight lines $p'_r p'_s$.

Since, by hypothesis,

for every r and s ($r \neq s$) between 2 and n , there is a t ($\neq r$ and s) between 2 and n such that $p_1 p_r p_s$ is a circle,

we obtain that,

for every r and s ($r \neq s$) between 2 and n , there is a t ($\neq r$ and s) between 2 and n such that $p'_r p'_s$ is a straight line.

Hence the Sylvester-Grünwald theorem gives that p'_i ($i = 2, 3, \dots, n$) all lie on a straight line.

Inverting back, p_i ($i = 1, 2, \dots, n$) lie on a circle.

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CHOOSING BETWEEN TWO SIMPLE HYPOTHESES AND THE CRITERION OF CONSISTENCY

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1. INTRODUCTION

Let $\{X_j\}$ ($j = 1, 2, \dots$ ad inf.) be a sequence of k -dimensional¹ chance variables and let H_0 and H_1 be two simple alternative hypotheses about the entire sequence of chance variables. That is to say, the hypothesis H_i ($i = 0, 1$) defines in a unique and consistent manner the joint probability distribution of any finite number of the chance variables $\{X_j\}$. We consider here the classical (non-sequential) problem of Inference where we have to decide between the two simple alternatives (H_0 and H_1) on the basis of a pre-determined number n of observations x_1, x_2, \dots, x_n on, say, the first n chance variables X_1, X_2, \dots, X_n . By a Decision Rule (or simply a rule) we mean a body of rules which for every n and every set of observations x_1, x_2, \dots, x_n (x_j is a point in a k -dimensional Euclidean space) tells us how to choose between the two alternatives. Although we shall ultimately consider the asymptotic properties of certain rules as $n \rightarrow \infty$, for the time being we fix our attention on a particular n and let M_n be the nk -dimensional Euclidean space of all sample points

$$\mathbf{x} = (x_1, x_2, \dots, x_n)$$

It is clear that if we alter a given rule on a set of sample points whose probability measure is zero under both H_0 and H_1 then the essential character of the rule remains unaltered. For, the two types of errors namely

α_{0n} = the probability of accepting H_1 when H_0 is true (the first type of error),

α_{1n} = the probability of accepting H_0 when H_1 is true (the second type of error)

remain the same and it is only on the basis of these two types of errors that different rules shall be compared.

Since it is clearly impossible to simultaneously minimise both α_{0n} and α_{1n} we may try to get rules that minimise a particular linear combination of the two errors, say

$$\bar{\alpha}_n = w_0 \alpha_{0n} + w_1 \alpha_{1n} (w_i > 0, w_0 + w_1 = 1).$$

It is clear that a rule that minimises $\bar{\alpha}_n$ is admissible in the sense that there exists no other rule for which the two types of errors are less than or equal to the corresponding errors of the first rule with the strict sign of inequality holding for at least one of the errors.

¹ It is only for the sake of some convenience of notation that we take every X_j to be a k -dimensional chance variable although without any loss of generality we could have assumed them to be one-dimensional.

The two weights w_0 and w_1 may be looked upon as the *a priori* probabilities for the two hypotheses H_0 and H_1 and then $\bar{\alpha}_n$ may be interpreted as the expected error. Thus the rule that minimises $\bar{\alpha}_n$ may be termed the Bayes' Rule.

It is possible to give a complete characterisation of the class of Bayes' Rules if the probability distributions of the sequence $\{X_j\}$ under H_0 and H_1 are either both absolutely continuous or are both discrete.

Let

$$f_{in} = f_i(x_1, x_2, \dots, x_n) \\ (n = 1, 2, \dots \text{ ad inf. } i = 0, 1)$$

be the probability density function or the frequency function of X_1, X_2, \dots, X_n under H_i .

Then the *a posteriori* probabilities for H_0 and H_1 after getting the sample \mathbf{x} are

$$P(H_0/\mathbf{x}) = \frac{w_0 f_{0n}}{w_0 f_{0n} + w_1 f_{1n}}$$

and

$$P(H_1/\mathbf{x}) = \frac{w_1 f_{1n}}{w_0 f_{0n} + w_1 f_{1n}}.$$

The over-all expected error will evidently be minimised if for every sample \mathbf{x} we minimise the conditional expected error and that will be achieved if we choose the hypothesis with the higher *a posteriori* probability. Thus the rule that will minimise $\bar{\alpha}_n$ is simply to choose H_0 or H_1 according as $w_0 f_{0n}$ is greater or less than $w_1 f_{1n}$ and when $w_0 f_{0n} = w_1 f_{1n}$ choose between H_0 and H_1 in any manner (say by tossing a coin) whatsoever.

Thus the following rule—

Rule I: 'Choose

$$H_0 \text{ if } f_{1n} < \lambda f_{0n} \\ (\lambda > 0) \\ H_1 \text{ if } f_{1n} > \lambda f_{0n}$$

and if $f_{1n} = \lambda f_{0n}$ then choose H_0 or H_1 in any manner whatsoever,' is a Bayes' Rule and minimises the average error

$$\bar{\alpha}_n = \frac{\lambda}{1+\lambda} \alpha_{0n} + \frac{1}{1+\lambda} \alpha_{1n} \dots \dots \dots (1.1)$$

The two rules namely (i) choose H_1 when $f_{1n} > 0$ and H_0 when $f_{1n} = 0$ and (ii) choose H_1 when $f_{0n} = 0$ and H_0 when $f_{0n} > 0$ may be considered to be limiting cases of Rule I for $\lambda = 0$ and $\lambda = \infty$ respectively.

Now the minimum value of (1.1) must not be greater than $\frac{\lambda}{1+\lambda}$ for there exists a rule for which $\alpha_{1n} = 0$. Similarly the minimum value of (1.1) is not greater than $\frac{1}{1+\lambda}$. Thus we have that for any Rule I

$$\alpha_{1n} \leq \min. \{ \lambda(1-\alpha_{0n}), 1-\lambda\alpha_{0n} \} \dots \dots \dots (1.2)$$

In particular we have $\alpha_{1n} \leq 1-\alpha_{0n}$ which means that every Bayes' Rule is unbiased.

It should be noted that if the set of points where $f_{1n} = \lambda f_{0n}$ be of probability measure zero under both H_0 and H_1 then the rule that minimises (1.1) is essentially

unique, i.e. if two rules R_1 and R_2 both minimise (1.1) then they can differ only in a set of probability measure zero (under both H_0 and H_1) and as such will have the same errors of the two types.

In our particular set-up it is not difficult to see that the class of rules of the type of Rule I is essentially complete, i.e. given any rule R outside the class we can find a rule R° within that class such that the two errors for R° are less than or equal to the two corresponding errors of R . We sketch below the method of proof.

Let α_{0n} and α_{1n} be the two errors for R . Now adjust λ in Rule I in such a way that the first type of error is equal to α_{0n} . The corresponding second type of error must be $\leq \alpha_{1n}$ since every Rule I is admissible. That λ can be so adjusted is easily seen as follows. Consider the function

$$g(\lambda) = P(f_{1n} > \lambda f_{0n}/H_0)$$

which is a monotonic non-increasing right continuous function of λ decreasing from

$$g(0) = P(f_{1n} > 0, f_{0n} \geq 0/H_0)$$

to

$$g(\infty) = \lim_{\lambda \rightarrow \infty} g(\lambda) = P(f_{1n} > 0, f_{0n} = 0/H_0) = 0.$$

Now if $g(0) < \alpha_{0n}$ then the following limiting type I Rule namely accept H_1 when $f_{1n} > 0$ and accept H_0 when $f_{1n} = 0$ will have a smaller first kind of error $g(0)$ and no second kind of error. If otherwise, i.e. if $g(0) \geq \alpha_{0n}$ then there will exist a smallest $\lambda = \lambda'$ such that $g(\lambda') \leq \alpha_{0n}$. If the sign of equality holds then the rule, namely, 'accept H_1 when $f_{1n} > \lambda' f_{0n}$ and accept H_0 if otherwise' will clearly satisfy our purpose. If the sign of inequality holds then that will imply that the set of points where $f_{1n} = \lambda' f_{0n}$ has a positive probability measure under H_0 and then we have to partially randomise our Decision Rule as follows:

$$\text{'Accept } H_1 \text{ if } f_{1n} > \lambda' f_{0n}$$

$$\text{accept } H_0 \text{ if } f_{1n} < \lambda' f_{0n}$$

and when $f_{1n} = \lambda' f_{0n}$ then accept H_1 or H_0 with probabilities p and $1-p$ respectively where p has to be so adjusted that

$$P(f_{1n} > \lambda' f_{0n}/H_0) + pP(f_{1n} = \lambda' f_{0n}/H_0) = \alpha_{0n}.$$

In the classical Neyman-Pearson procedure the first kind of error α_{0n} is controlled at a given level α and the second type of error α_{1n} is minimised. The solution is clearly a Rule I with a properly adjusted λ as just explained. If

$$P(f_{1n} = \lambda f_{0n}/H_0) = 0$$

for all $\lambda > 0$ then the Neyman-Pearson Rule (Rule II) for any level of significance $\alpha \leq g(0)$ will be essentially non-randomised. Otherwise we may have to take recourse to partially randomised rules (as indicated before).

The Minimax Rule (Rule III) is one which makes the maximum of the two errors α_{0n} and α_{1n} the minimum (if we give different weights say c_0 and c_1 to the two types of errors then the Minimax Rule minimises the maximum of $c_0\alpha_{0n}$ and $c_1\alpha_{1n}$). It is clear that if in Rule I we so adjust λ that $\alpha_{0n} = \alpha_{1n}$ then, because of the admissibility of Rule I, the rule minimises the maximum error (risk). That such a λ always exists is seen as before. If the probability measure of the set of points where $f_{1n} = \lambda f_{0n}$ be not zero under H_0 and/or H_1 for some λ then we may

have to partially randomise our rule in order to attain the equality of two types of errors.

We note that whereas in Rule I, λ is independent of n in Rules II and III, λ becomes a function of n .

2. CONSISTENT RULES

A Decision Rule may be called consistent if as $n \rightarrow \infty$ the two types of errors α_{0n} and α_{1n} simultaneously tend to zero. Since in the classical Inference procedure (Rule II) the first type of error α_{0n} is kept at a given level α we may call a classical rule consistent if for any level of significance α ($0 < \alpha < 1$) the corresponding second type of error $\alpha_{1n} \rightarrow 0$ as $n \rightarrow \infty$.

Under many situations there do not exist any consistent Decision Rule. For example consider the following situation where X_j 's are one-dimensional variables and where for any n ($n = 1, 2, \dots$ ad inf.) the joint probability distribution of X_1, X_2, \dots, X_n is multivariate normal with the same dispersion matrix A_n but with different means under the two hypotheses H_0 and H_1 . Without any loss of generality we may suppose that the mean of X_j under H_0 is zero for every j . Thus we have

$$f_{0n} = (2\pi)^{-\frac{n}{2}} |A_n|^{-\frac{1}{2}} \exp \left\{ -\frac{1}{2} \mathbf{x} A_n^{-1} \mathbf{x}' \right\}$$

and

$$f_{1n} = (2\pi)^{-\frac{n}{2}} |A_n|^{-\frac{1}{2}} \exp \left\{ -\frac{1}{2} (\mathbf{x} - \boldsymbol{\xi}) A_n^{-1} (\mathbf{x} - \boldsymbol{\xi})' \right\}$$

where A_n is the common dispersion matrix and $\boldsymbol{\xi} = (\xi_1, \xi_2, \dots, \xi_n)$ is the mean vector under H_1 .

Let

$$\begin{aligned} Z_n = \log \frac{f_{1n}}{f_{0n}} &= -\frac{1}{2} \left\{ (\mathbf{x} - \boldsymbol{\xi}) A_n^{-1} (\mathbf{x} - \boldsymbol{\xi})' - \mathbf{x} A_n^{-1} \mathbf{x}' \right\} \\ &= \mathbf{x} A_n^{-1} \boldsymbol{\xi}' - \frac{1}{2} D_n^2 \quad \dots \quad \dots \quad \dots \quad \dots \quad (2.1) \end{aligned}$$

where $D_n^2 = \boldsymbol{\xi} A_n^{-1} \boldsymbol{\xi}'$ is the Mahalanobis' distance D^2 between the two hypotheses when we fix our attention on the first n chance variables only.

Writing $L = \log \lambda$ we can write Rule I as

'Accept H_0 if $Z_n < L$

and

accept H_1 if $Z_n > L$ '.

(The set of points where $Z_n = L$ is of probability measure zero under both H_0 and H_1 and as such need not be considered.)

Now it is easily verified that

$$Z_n | H_0 \sim N \left(-\frac{1}{2} D_n^2, D_n \right) \quad \dots \quad \dots \quad \dots \quad (2.2)$$

and

$$Z_n | H_1 \sim N \left(\frac{1}{2} D_n^2, D_n \right) \quad \dots \quad \dots \quad \dots \quad (2.3)$$

in this case the two types of errors corresponding to Rule I are

$$\begin{aligned}\alpha_{0n} &= P(Z_n > L | H_0) \\ &= P\left(N(0, 1) > \frac{L + \frac{1}{2}D_n^2}{D_n}\right)\end{aligned}$$

and

$$\begin{aligned}\alpha_{1n} &= P(Z_n < L | H_1) \\ &= P\left(N(0, 1) < \frac{L - \frac{1}{2}D_n^2}{D_n}\right).\end{aligned}$$

For the particular case where $\lambda = 1$ in Rule I (i.e. $L = 0$ here) the above rule minimises $\frac{1}{2}(\alpha_{0n} + \alpha_{1n})$ and for this case the two types of errors are equal (i.e. this is also the Minimax Rule) and is

$$P\left(N(0, 1) > \frac{1}{2}D_n\right) \quad \dots \quad \dots \quad \dots \quad (2.6)$$

If we increase n then the minimum attainable value for $\frac{1}{2}(\alpha_{0n} + \alpha_{1n})$ can never increase because the class of rules that make use of observations on the first $n+1$ chance variables obviously contains as a sub-class the rules that make use of only the first n observations. Thus (2.6) is a non-increasing function of n and so we have an indirect proof of the fact that D_n is a monotonic non-decreasing function of n . From (2.4) and (2.5) we then at once have that the necessary and sufficient condition that $\alpha_{in} \rightarrow 0$ ($i = 0, 1$) is $D_n \rightarrow \infty$. Since every Rule I is admissible it follows that there can exist a consistent rule if and only if $D_n \rightarrow \infty$. If we adopt the classical test procedure where α_{0n} is kept at a given level α then in the above rule (which then becomes a Rule II) we have to choose

$$L = L_n = -\frac{1}{2}D_n^2 + \gamma D_n \quad \dots \quad \dots \quad \dots \quad (2.7)$$

where γ is the upper 100α % value of the standard Normal Distribution. Then the second type of error is

$$\alpha_{1n} = P(N(0, 1) < -D_n + \gamma) \quad \dots \quad \dots \quad \dots \quad (2.8)$$

and this tends to zero if and only if $D_n \rightarrow \infty$.

We thus have the following:—

Theorem:—If under hypothesis H_i ($i=0, 1$) the joint probability distribution of X_1, X_2, \dots, X_n ($n = 1, 2, \dots$ ad inf.) be multivariate normal with mean vector $\xi_n^i = (\xi_1^i, \xi_2^i, \dots, \xi_n^i)$ and common dispersion matrix A_n then a necessary and sufficient condition for the existence of a consistent test is that the Mahalanobis distance

$$D_n^2 = (\xi_n^0 - \xi_n^1)A_n^{-1}(\xi_n^0 - \xi_n^1)'$$

tends to infinity as $n \rightarrow \infty$.

For example let the X 's be independent normal variables and let

$$X_j | H_0 \sim N(0, \sigma_j)$$

and

$$X_j | H_1 \sim N(\xi_j, \sigma_j) \quad j = 1, 2, \dots \text{ad inf.}$$

Then a necessary and sufficient condition for the existence of a consistent test rule is that the series $\sum (\xi_n^2 / \sigma_n^2)$ is divergent.

3. THE CASE WHEN THE X_j 's ARE INDEPENDENT AND IDENTICAL

In the particular case where the X_j 's are independently and identically distributed k -dimensional chance variables it is very easily proved that there always exists consistent test rules. For, let S be a set in the k -dimensional sample space of X_j such that

$$p_0 = P(x_j \in S | H_0) < P(x_j \in S | H_1) = p_1 \quad \dots \quad \dots \quad (3.1)$$

(such an S obviously exists excepting in the trivial case where H_0 and H_1 defines the same probability measure for X_j).

Define y_j by

$$\begin{aligned} y_j &= 1 \text{ if } x_j \in S, \\ &= 0 \text{ otherwise.} \end{aligned}$$

Clearly the y_j 's are independent random observations from a Binomial population with mean p_0 under H_0 and mean p_1 under H_1 ($p_0 < p_1$) and so the following rule namely.

$$\begin{aligned} \text{Accept} \quad & H_0 \text{ if } \frac{1}{n} (y_1 + \dots + y_n) < \frac{1}{2} (p_0 + p_1) \text{ and} \\ \text{accept} \quad & H_1 \text{ if } \frac{1}{n} (y_1 + \dots + y_n) > \frac{1}{2} (p_0 + p_1) \end{aligned}$$

is a consistent rule (as is easily verified).

It should be noted that the above proof is quite general and does not require to assume that the underlying probability measures are either both absolutely continuous or both discrete.

When this assumption is made it follows that every Rule I is consistent. For Rule I minimise (for all n) the average error $\bar{\alpha}_n$ as given by (1.1) and as there exists a consistent rule it follows that

$$\inf \bar{\alpha}_n \rightarrow 0 \quad \text{as } n \rightarrow \infty$$

and so the two errors corresponding to every Rule I tend to zero separately. That every Rule II and III also is consistent follows similarly from the existence of a consistent rule.

Let $f_i(x_j)$ be the probability density function or the frequency function of X_j under hypothesis H_i ($i = 0, 1, j = 1, 2, \dots$ ad inf.) and let

$$z_j = \log \frac{f_1(x_j)}{f_0(x_j)} \quad j = 1, 2, \dots \text{ ad inf.}$$

(We put $z_j = +\infty$ when $f_1 > f_0 = 0$ and $z_j = -\infty$ when $f_0 > f_1 = 0$. The set of points where $f_0 = f_1 = 0$ may be ignored as that is of probability measure zero under both H_0 and H_1 . By definition $\pm\infty \pm\infty = \pm\infty$ but the operation $\pm\infty \mp\infty$ is not defined).

$$\text{Let} \quad Z_n = z_1 + z_2 + \dots + z_n.$$

(The set of points where Z_n is not defined is again of probability measure zero under both H_0 and H_1 .)

Rule I can now be written as

$$\begin{aligned} \text{'Accept} \quad & H_0 \text{ if } Z_n < L \\ \text{accept} \quad & H_1 \text{ if } Z_n > L \end{aligned} \quad (L = \log \lambda)$$

and when $Z_n = L$ choose between H_0 and H_1 by any rule whatsoever.'

We now make the assumption that z_j has finite means and variances under both H_0 and H_1

$$\begin{aligned}\text{Let} \quad \mu_0 &= -E(z_j | H_0) = E\left(\log \frac{f_0}{f_1} | H_0\right) \\ \mu_1 &= E(z_j | H_1) = E\left(\log \frac{f_1}{f_0} | H_1\right) \\ \text{and} \quad \sigma_i^2 &= V(z_j | H_i) \quad (i = 0, 1).\end{aligned}$$

Since

$$E\left(\frac{f_1}{f_0} | H_0\right) = 1$$

it follows from the convexity of the log function that

$$E\left(\log \frac{f_1}{f_0} | H_0\right) < 0$$

(excepting in the trivial case where $f_1 = f_0$ a.e.w.) and hence it follows that $\mu_0 > 0$. Similarly $\mu_1 > 1$.

If in Rule I we so adjust L as to get a Rule II then we have

$$P(Z_n < L_n | H_0) = \alpha$$

(the constant first type of error) for all n . Since by the weak law of large numbers $\frac{1}{n} Z_n | H_0 \rightarrow -\mu_0$ in probability sense it follows that

$$L_n = -n\mu_0 + o(n)$$

and so from (1.2) we have that the corresponding second type of error

$$\alpha_{1n} < (1 - \alpha)e^{-n\mu_0 + o(n)}.$$

The above asymptotic upper bound for α_{1n} can clearly be lowered if we make use of the other constants μ_1 , σ_0 , and σ_1 and use the Central Limit Theorem. However we leave aside this unsymmetric (w.r.t. the two hypotheses) decision procedure and study the symmetric Rule III (the Minimax Rule).

In Rule III we adjust λ (i.e. L) in Rule I in such a way as to make the two errors α_{0n} and α_{1n} equal. Two hypotheses H_0 and H_1 may be regarded as rather distant ones if this common value (the minimax error) tends to zero rather rapidly as $n \rightarrow \infty$. Thus the rapidity with which this common value α_{0n} ($= \alpha_{1n}$) approaches zero may be taken to be a measure of the distance between two hypotheses.

For a particular choice of $L = L_n$ we have approximately (i.e. ignoring the set of points where $Z_n = L_n$)

$$\begin{aligned}\alpha_{0n} &= P(Z_n > L_n | H_0) \\ &= P\left(\frac{Z_n + n\mu_0}{\sqrt{n}\sigma_0} > \frac{L_n + n\mu_0}{\sqrt{n}\sigma_0} | H_0\right)\end{aligned}$$

and

$$\begin{aligned}\alpha_{1n} &= P(Z_n < L_n | H_1) \\ &= P\left(\frac{Z_n - n\mu_1}{\sqrt{n}\sigma_1} < \frac{L_n - n\mu_1}{\sqrt{n}\sigma_1} | H_1\right).\end{aligned}$$

Now by the Central Limit Theorem

$$\frac{Z_n - n\mu_0}{\sqrt{n}\sigma_0} \mid H_0 \xrightarrow{d} N(0, 1)$$

and

$$\frac{Z_n - n\mu_1}{\sqrt{n}\sigma_1} \mid H_1 \xrightarrow{d} N(0, 1).$$

If we choose L_n in such a way that

$$\frac{L_n + n\mu_0}{\sqrt{n}\sigma_0} = - \frac{L_n - n\mu_1}{\sqrt{n}\sigma_1}$$

then for all large n , α_{0n} will be approximately equal to α_{1n} and this common value will be approximately equal to

$$P \left\{ N(0, 1) > \sqrt{n} \frac{\mu_0 + \mu_1}{\sigma_0 + \sigma_1} \right\}.$$

Thus it appears that the larger is the constant $(\mu_0 + \mu_1)/(\sigma_0 + \sigma_1)$ the smaller (asymptotically) is the minimax error. And so this constant may be taken to be a measure of the discrepancy (or distance) between H_0 and H_1 . In the particular situation where X_j ($j = 1, 2, \dots$ ad inf.) under the hypothesis H_i ($i = 0, 1$) is a k -dimensional multivariate normal variable with dispersion matrix A_n (independent of i) and mean vector $\xi^i = (\xi_1^i, \dots, \xi_k^i)$ then it is easily verified that

$$\mu_0 = \mu_1 = \frac{1}{2} D^2$$

and

$$\sigma_0 = \sigma_1 = D$$

where

$$D^2 = (\xi^1 - \xi^0) A_n^{-1} (\xi^1 - \xi^0)' \quad (\text{Mahalanobis } D^2)$$

and so

$$\frac{\mu_0 + \mu_1}{\sigma_0 + \sigma_1} = \frac{1}{2} D.$$

Actually in this case the minimax error is exactly equal to

$$P \left\{ N(0, 1) > \frac{1}{2} \sqrt{n} D \right\}.$$

SUMMARY

The classical problem of choosing between two simple hypotheses on the basis of a sample x_1, x_2, \dots, x_n of predetermined size n has been considered in some detail. A Decision Rule (defined for all n) is called a consistent one if we can control the two types of errors within arbitrary limits by taking n to be sufficiently large. In the particular situation where the x 's are observations on independent and identically distributed chance variables there always exists consistent rules but under other situations there may not exist any consistent rules. A new definition of distance between two hypotheses is given. Mahalanobis' D becomes a particular case in the case of multivariate normal distributions with common dispersion matrix. The introduction to this paper is of an expository nature intended to make the later discussion easier to follow.

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STUDIES ON CYTOCHEMISTRY OF HORMONE ACTION.

PART XIII. CHANGES IN THE DISTRIBUTION OF ALKALINE PHOSPHATASE IN THE GENITAL ORGANS OF THE FEMALE RAT AFTER ADRENALECTOMY AND AFTER REPLACEMENT THERAPY

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INTRODUCTION

Dempsey *et al.* (1949) reported that alkaline phosphatase was demonstrable in the Graafian follicles, corpora lutea and in the interstitium of the rat's ovary. The enzyme activity, however, totally disappeared from these elements after hypophysectomy but was re-established after replacement therapy with pituitary powder.

Considerable amount of alkaline phosphatase normally occurred in the uterus of mice. The sites of activity were the lumen, mucosa, endometrial stroma and the endothelium of the stromal capillaries (Atkinson and Elftman, 1947). Ovariectomy caused a loss of enzyme activity from these components which, however, was restored on replacement therapy with estrogen. The pattern of distribution of alkaline phosphatase in the uterus of rat was more or less similar to that of the mouse (Dempsey *et al.*, 1949). After hypophysectomy the enzyme disappeared in a likewise manner from the uterine components but was brought back to the normal level after administration of pituitary powder. Thibault and Soulairac (1948) observed that alkaline phosphatase activity was very high in the vaginal mucosa of rats but was comparatively low in the uterus. There was a total loss of the enzyme from the vagina after ovariectomy but its activity was considerably augmented in the uterine horns. Estrogen therapy caused a re-appearance of normal phosphatase picture of the vagina but that of the uterus was restored only when progesterone was administered in addition to estrogen. In rhesus monkey treated with estrogen alone, alkaline phosphatase was found mainly in the endometrial glands and the mucosal epithelium of the uterus (Atkinson and Engle, 1947). When estrogen was followed by progesterone, there was a marked reduction of enzyme activity from the surface epithelium and from the portion of the glands lying in the functionalis. These authors also noted considerable variations in the phosphatase content of these tissues during the menstrual cycle in the human. Talmage (1949) reported that estradiol caused a mobilization of phosphatase activity in the stratified epithelium bordering the lumen of the cervix in the rat. Kamell and Atkinson (1948) found only negligible amounts of the enzyme in the vaginal epithelium of the ovariectomized mice. Estrogen therapy in such animals resulted in a marked increase in phosphatase activity of this component.

As the adrenals are known to have a controlling influence over the functioning of the genital organs (Hartman and Brownell, 1949), it seemed of interest to us to study the effect of adrenalectomy and replacement therapy on the distribution of alkaline phosphatase in the ovary and the uterus of rats.

EXPERIMENTAL PROCEDURE

Adult female rats, weighing 130 ± 8 gms., were used in this study. A total of 18 animals were used of which 12 were adrenalectomized and the remaining 6 were left intact to serve as controls. A group of 6 adrenalectomized animals was treated with desoxycorticosterone acetate (DCA) in a dosage of 2.5 mgm. daily (in 0.5 c.c. of sterile sesame oil) per animal, for 7 days. The hormone therapy commenced on the 13th day after the operation. An equal number of adrenalectomized animals were injected with sesame oil alone in a similar manner. All the operated animals were given 0.9% physiological saline solution instead of water for drinking purposes. The group of adrenalectomized animals which was not injected with DCA received the saline solution throughout the experimental period but the hormone-treated group was given saline only for a period of 12 post-operative days after which it was replaced by plain water. All the injections were given by the intramuscular route.

Autopsy followed 24 hours after the final treatments. The ovary and the uterus were carefully dissected out and fixed immediately in chilled 80% ethyl alcohol and in 10% formal-saline. After dehydration and imbedding in paraffin, serial sections were prepared. The tissues fixed in 10% formal-saline were stained with Ehrlich's hematoxylin followed by alcoholic eosin. The sections of the tissues fixed in ethyl alcohol were processed according to the technique of Gomori (1941) for the demonstration of alkaline phosphatase. The sites of phosphatase activity in tissue sections are marked by the deposition of cobalt sulfide in fine black granules. In order to allow critical observation of these granular deposits no counterstain was used. The sections were dehydrated and mounted in the usual manner.

RESULTS

A. Normal Controls

Ovary.—The cellular elements of the interstitium show an intense phosphatase activity in the nucleus but the cytoplasm stains only in a faint manner. The germinal epithelium and the endothelium of the interstitial capillaries also give a strong positive reaction for the enzyme. In the Graafian follicles, the phosphatase is present in a most prominent manner in the nucleus of the granulosa cells, the ovum and in the theca. On the other hand, the immature oocytes show a positive reaction only in the nucleus of the granulosa cells. A somewhat similar pattern is displayed by the atretic follicles which in addition to the phosphatase-rich granulosa cells, show an intense activity in the theca. In a typical active corpus luteum, considerable amounts of the enzyme are present in the nucleus of the luteal cells and in the endothelium of the vascular sinusoids (Pl. XXXVI, fig. 1). The cytoplasm of the luteal cells, however, are negative for enzyme activity.

Uterus.—Only the endothelium of the capillaries in the serosa and the myometrium stains positively for alkaline phosphatase. Other elements of these parts are totally devoid of enzyme activity. In the endometrium, strong positive reactions are given by the nucleus of the mucosal epithelium whereas the cytoplasm stains in a less intense manner. There is also a mobilization of the enzyme at the luminal end of the epithelial cells. The stromal cells and the glands of the endometrium show mostly nuclear phosphatase activity. The endothelium of the endometrial capillaries, however, react in a strong positive manner (Pl. XXXVI, fig. 2).

B. Adrenalectomized

Ovary.—The interstitial cells and the atrophic germinal epithelium are devoid of phosphatase activity but the vascular endothelium continues to give a positive reaction for the enzyme. There is considerable inhibition of follicular development and a frequent occurrence of atretic follicles. However, the pattern of distribution

of the enzyme remains unchanged in these elements. In the corpus luteum, on the other hand, there is a total loss of enzyme activity from the luteal cells but the endothelium of the sinusoids continues to give a positive reaction (Pl. XXXVI, fig. 3).

Uterus.—The pattern of distribution of alkaline phosphatase in the serosa and the myometrium is similar to that of the normal controls. In the endometrium, on the other hand, only negligible amounts of the enzyme are present in the nucleus of the mucosal epithelium (Pl. XXXVI, fig. 4). The nucleus of the atrophic endometrial glands too stains in a faint manner. There is a general loss of phosphatase activity from the cellular elements of the stroma but the endothelium of the sinusoids continues to give a positive reaction for the enzyme.

TABLE 1

The distribution of alkaline phosphatase in the genital organs of normal and experimental rats

				Normal controls	Adrenal-ectomized	Adrenal-ectomized plus DCA
OVARY						
<i>Interstitial cells</i>	..	..		+ⁿ + ⁿ	—	+ ⁿ + ⁿ
<i>Endothelium of the interstitial capillaries</i>	..	..		++	+	+++
<i>Germinal epithelium</i>	..	..		++	—	++
<i>Graafian follicles—</i>						
Granulosa cells	..	..		+ⁿ + ⁿ	+ ⁿ + ⁿ	+++
Ovum	..	..		++	++	++
Theca	..	..		++	++	++
<i>Oocytes—</i>						
Granulosa cells	..	..		+ⁿ + ⁿ	...	+ ⁿ + ⁿ
<i>Atretic follicles—</i>						
Granulosa cells	..	..		+ⁿ + ⁿ	+ ⁿ + ⁿ	+ ⁿ + ⁿ
Theca	..	..		++	++	++
<i>Corpus luteum—</i>						
Luteal cells	..	..		+ⁿ + ⁿ	—	+++
Endothelium of the sinusoids	..	..		++	+	+++
UTERUS						
<i>Serosa and myometrium—</i>						
Endothelium of the capillaries	..	..		+	+	+
Other components	..	..		—	—	—
<i>Endometrium—</i>						
Epithelium	..	..		+ⁿ + ⁿ	+ ^{nt}	++
Stromal cells	..	..		+ⁿ	+ ^{nt}	++
Glandular epithelium	..	..		+ⁿ	+ ^{nt}	++
Endothelium of the capillaries	..	..		++	+	++

Legend:—

- ++ = Strong phosphatase activity.
- + = Positive Reaction.
- +++ = Very intense enzyme activity.
- +ⁿ+ⁿ = Mostly strong nuclear phosphatase activity.
- +ⁿ = Positive reaction, mostly in the nucleus.
- +^{nt} = Only a trace of nuclear phosphatase activity.
- = Negative reaction.

C. Adrenalectomized plus DCA.

Ovary.—The inhibition of follicular development and the frequent occurrence of atretic follicles which are common features of the ovary of adrenalectomized animals, are absent. The phosphatase picture of the ovary, too, is similar to that of the normal controls. However, the granulosa cells, the luteal cells and the endothelium of the sinusoids stain in a more intense manner than in the normal controls (Pl. XXXVI, fig. 5; table 1).

Uterus.—The phosphatase reactions of the serosa and the myometrium are similar to those of the normal controls. In the endometrium, the epithelial cells stain intensely both in the nucleus and in the cytoplasm. The endometrial glands, stromal cells and the endothelium of the stromal sinusoids show a stronger phosphatase activity than in the controls (Pl. XXXVI, fig. 6).

DISCUSSION

The present study has demonstrated clearly that there are considerable amounts of alkaline phosphatase in the ovary and the uterus of normal rats. Adrenalectomy causes a loss of enzyme activity from these tissues but replacement therapy with DCA adequately restores their normal phosphatase complements.

A point of considerable interest is the inhibition of follicular development in the adrenalectomized rats. An accelerated rate of follicular atresia and the atrophy of the germinal epithelium are items which also should be reckoned in this connection. A consequence of these untoward effects of adrenal insufficiency is reflected in the uterus. The endometrial glands of this tissue shows a definite degenerated condition in contrast to the normal functioning ones of the unoperated animals. These findings are in general agreement with similar conditions reported in the genital organs of the female rat after adrenalectomy (*see* Hartman and Brownell, 1949). It is, however, significant that the present cytochemical observations record a loss of phosphatase activity mainly from the germinal epithelium and the corpora lutea of the adrenalectomized rats. Incidentally, these are two most vital components of the ovary as they are concerned respectively, with the formation of ova and the secretion of progesterone (Turner, 1948). The loss of phosphatase from the atrophic germinal epithelial cells is probably associated with an inhibition of proliferative activity of these elements which is essential for the formation of ova. The disappearance of the enzyme from the luteal cells may be similarly responsible for a reduced development and activity of these cells. This concept is supported by our finding that the endometrial glands of the uterus are atrophic in nature in the adrenalectomized animals. As the dependence of these structures on the secretory activity of the corpus luteum is well known (Turner, 1948), the loss of phosphatase activity from the luteal cells appears extremely significant. Apart from these, the general reduction of enzyme activity from the uterus after adrenalectomy or its restoration on replacement therapy with DCA, are probably cytochemical consequences of similar phenomena noticeable in the ovary. It may be argued further that the inhibition of phosphatase activity in the ovary due to adrenal insufficiency, is perhaps a facet of the intricate enzymic mechanism responsible for the physiological changes in this organ and that the reactions of the uterus are secondary manifestations of these changes.

SUMMARY

Adrenalectomy causes a loss of phosphatase activity from the ovary and the uterus of rats. DCA therapy restores the enzyme to its original distribution and intensity. The possible significance of phosphatase changes under these conditions is discussed.



1



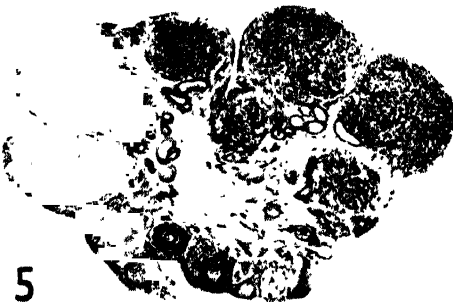
2



3



4



5



6

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EXPLANATION OF PLATE XXXVI

(All figures are photomicrographs and are magnified $\times 25$)

- FIG. 1. Section through the ovary of a normal rat. Note the distribution of alkaline phosphatase.
- FIG. 2. Section through the uterus of a normal rat. Note the distribution of the enzyme.
- FIG. 3. Section through the ovary of an adrenalectomized rat. There is a loss of phosphatase activity from the interstitium and the corpora lutea. Compare with fig. 1.
- FIG. 4. Section through the uterus of an adrenalectomized rat. Note the general loss of phosphatase activity. Compare with fig. 2.
- FIG. 5. Section through the ovary of an adrenalectomized rat treated with DCA. Note intense phosphatase activity in some of the elements.
- FIG. 6. Section through the uterus of an adrenalectomized rat treated with DCA. Compare with fig. 2.

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